Vol. 1 MAY, 1918 No. 5

Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries.

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Published Monthly by the
AMERICAN CERAMIC SOCIETY

Publication Office
211 Church St., Easton, Pa.

Editorial Office
Rutgers College, New Brunswick, N. J.

SIX DOLLARS PER YEAR (Foreign Postage Additional) *SINGLE NUMBERS, SIXTY CENTS*

Entered as second-class matter, July 15, 1918, at the post office at Easton, Pa., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized August 16, 1918.

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JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly journal devoted to the arts and sciences related to the silicate industries.

Vol. 1 **May, 1918** **No. 5**

EDITORIALS.

CHEMICAL STONEWARE.

The manufacture of chemical stoneware has been greatly influenced and stimulated by the demands of the war and the importance of this product in the manufacture of certain war essentials, such as acids, heavy chemicals, high explosives, medicines, etc., has proven second to no other product. In the new and important industry of the fixation of atmospheric nitrogen, which the Government is developing upon such an enormous scale, chemical stoneware will play an important and leading role. Chemical stoneware is used on a large scale in the production of picric acid and of nitric acid. Perhaps no development of the war holds as much popular and scientific interest as the production of poison gases and gas shell. Here again chemical stoneware is necessary to large scale production and without it the manufacture of this new war essential would be greatly handicapped.

When we consider that chemical stoneware really takes the place of chemical glassware in large scale production, its uses and necessary properties are better understood. In the laboratory the chemist uses chemical glassware for his work but the use of chemical glassware in factory operations is out of the question. Here, chemical stoneware enters and its manufacture into the complicated shapes required is little short of wonderful. In order that it may stand up under factory conditions—which may include corrosion, high temperatures, high pressures, and rapid

heating and cooling—the quality and construction of the ware must be of the very highest grade.

The entire system of an acid plant is often made fom this ware. Starting from the still, all of the pipes, cooling coils, pumps, elevators, containers, towers, condensers and collectors are so constructed that the acid is in contact only with acid-proof stoneware throughout the system. The automatic acid pumps have valves and pistons of stoneware—ground to fit accurately. The exhausters have stoneware casings, propellers and driving shafts—accurately fitted with ground joints. To complete the cycle, the acid will soon be conveyed to the consumer in chemical stoneware carboys.

Before the war, it was generally believed that the best stoneware could be made only in Germany—where the development of the industry had received much care and attention. Some of the highest grade stoneware on the market in this country at that time was made from raw clay bodies imported from Germany. With the outbreak of the war, however, it became necessary to develop sources of raw materials and this has been done to a highly successful degree. At the present time it may be stated that there is being produced in this country chemical stoneware which is superior in every respect to any made in Germany previous to the war. The manufacturers of this essential product have met the increased war demands in splendid style and all requirements have been quickly met. Chemical stoneware will undoubtedly continue to play a leading rôle in our greatly expanded chemical industry.

THE AMERICAN CERAMIC SOCIETY AND THE WAR.

It is gratifying to note that the American Ceramic Society, through the efforts of its War Service Committee, has received recognition by the War Industries Board through the appointment of Homer F. Staley, President of the Society, as Technical Advisor in Ceramics to the Board. Mr. Staley will coöperate with the other members of the staff dealing with the problems arising in the production of such ceramic products as optical glass, chemical stoneware, tableware, chemical porcelain, building

materials, and the production and importation of white-burning clays.

The importance of ceramic products in the manufacture of a great many of the war essentials is unquestioned. Up to this time our members have individually and collectively given their services toward the solution of the many war problems arising in the industry but there has been a serious lack of team-work and coöperation. Mr. Staley's appointment as Technical Advisor to the War Industries Board fills a long-felt want and gives to the American Ceramic Society, the one great technical society representing a large and very essential industry, the recognition it deserves.

WAR CURRICULUM IN CERAMIC ENGINEERING

It is interesting to note that the Committee on Ceramic Chemistry of the National Research Council is now preparing a War Curriculum in Ceramic Engineering for those Colleges and Universities maintaining units of the Student Army Training Corps and having Departments of Ceramic Engineering. After consultation with the Ceramic Departments involved, a tentative curriculum has been agreed upon and courses in this branch of engineering will be afforded. The Curriculum in Ceramic Engineering as outlined includes most of the courses now offered. However, special courses in Combustion and Fuel Engineering are notable additions. It is to be hoped that a sufficient number of the students will take advantage of the Ceramic Engineering courses so that the future demand for technically trained Ceramic Engineers will be supplied.

ORIGINAL PAPERS AND DISCUSSIONS.

A STUDY OF DRAFT MOVEMENTS IN FLUES.

By Edwin H. Fritz, Derry, Pa.

Introduction.

In a paper by C. B. Harrop[1] on "The Inadequacy of Static Pressure Draft Gages," he proved beyond question that the ordinary draft gage is apt to be misleading, and that its readings do not indicate the rate of movement of gases in the kiln because the pressure, producing this movement, is entirely different from the static pressure measured by the draft gage. The pressure causing the rate of movement or velocity of flow of gases is called the "velocity pressure" and when added to the static pressure—which is the pressure required to overcome the resistance offered to the flow—gives the total pressure or draft intensity of a stack. The "velocity pressure" is not apt to vary directly with the static pressure and for this reason cannot be equal to it. Therefore, if the static pressure reading, as obtained by a draft gage, is assumed to be the velocity pressure, the results will be erroneous.

As an illustration, Harrop discussed a stack having a grate bar furnace built into its base, and with the internal gases at a temperature of 600° F. If the fire and ash doors were closed, the draft intensity was 0.6 inch (water column). If the ash doors were opened and the friction in the chimney was considered as negligible, a velocity pressure of 0.3 inch was developed. At the same time, the draft gage would show a reading of 0.3 inch over the grates. Assuming a constant stack temperature and a thicker fuel bed offering 50 per cent. more resistance to the passage of the air—only three-fourths as much air would pass through and the corresponding velocity pressure would be less than before. The draft gage

[1] *Trans. Am. Ceram. Soc.*, **18**, 223 (1916).

recording the static pressure, or the difference between the total draft intensity and the velocity pressure, would read higher. Thus he pointed out that by thickening the fuel bed and, therefore, by decreasing the volume of gas flowing through the grates, the draft gage gave a higher reading. This higher reading would erroneously indicate a better draft.

Investigation.

It seems that the inconsistency and tendency of the draft gages to mislead is not quite generally known and as there are many in actual use the necessity for a better method for its use is evident. Accordingly, this investigation was undertaken with a view to either finding a way to make the draft gage indicate the rate of movement of the gases or to find some other way of measuring the volume of gas passing through a flue.

The method selected was that suggested by Harrop[1] at the close of his paper and also mentioned in the discussion of his paper. Briefly, the measurement of the static pressure between two points in a flue was taken as a basis—the friction between the two points always being constant with any given velocity of gases.

The apparatus used consisted of static pressure tubes inserted into a flue at the two points and each connected to one end of a U-tube, as used on the draft gage. A differential reading giving the friction between the two points was then taken. As long as no air passes through the flue, there is no friction and consequently the liquid in both tubes would stand at the same level. However, as soon as air passes through, there is friction and this friction would be measured by the differential reading on the gage. It is evident that the differential reading would vary directly as the volume of gas passing through the flue, since the greater the volume the greater the velocity of the gas and the greater, therefore, the resistance offered by the flue. However, since the velocity of the gas in the flue between a kiln and stack is only about 600 feet per minute, the two points in the flue would have to be a great distance apart in order to get an appreciable reading—a straight flue offering but little resistance. In fact, the full length of most kiln

[1] *Trans. Am. Ceram. Soc.*, **18**, 223 (1916).

flues would be too short to give sufficient resistance. It was therefore necessary to devise a different method for providing this resistance.

Apparatus.

The use of a diaphragm with an orifice, as used by the Bailey Meter Company and others in their flow meters, used primarily for the measurement of steam and water pressure, was thought especially desirable. There appeared to be no reason why this method could not be made applicable in the measurement of the amount of gas flow in a flue system. It has been found to be extremely accurate by the Bailey Meter Company in their meters and preferable to the Pitot tube.

The Pitot Tube.

The Pitot tube is not suitable for measuring the flow of gases at the low velocities usually found in flues and requires long runs of straight flow before it will give accurate results. It is also difficult to get an average reading with the Pitot tube, especially when the cross section of the flue is irregular. The latter disadvantage would undoubtedly be met in kiln flues, for the flue between kiln and stack is often quite short and since a straight flue is needed on both sides of the tube, this instrument would hardly be practical. Besides, it must be used very carefully in order to get accurate results. Therefore, the use of a diaphragm with orifice in a flue, if it could be made applicable, seemed to be the most practical.

Experimental Flue.

It was considered inadvisable to carry on the experimental work with a flue connected to a stack because no means of controlling the draft and of testing different sized flues were available. An electrically driven fan was therefore connected at its inlet to a wooden flue (Fig. 1) thus producing an induced draft. The wooden flue was $35'' \times 35'' \times 12'$ in length and was made as air-tight as possible. It had but three sides, the concrete floor serving as a bottom. A brick flue was not considered necessary—since only the drop in pressure through the orifice was

measured and all other rubbing surfaces would have but little effect.

A brick wall was built about nine feet from the fan inlet in the flue. A greater distance than this was desirable but more space was not available. The orifice in the center of the diaphragm was made square. The brick were laid in cement mortar, and all cracks and openings between the diaphragm and the flue were made air-tight.

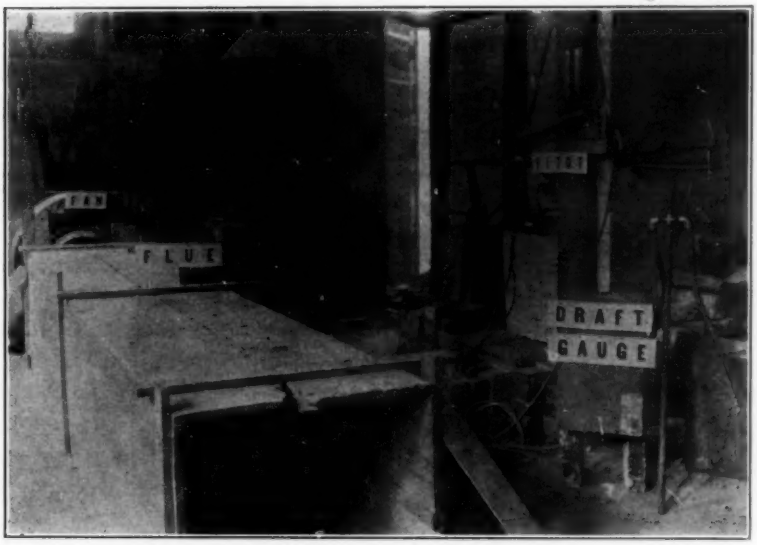

FIG. 1.

Orifices of two sizes were tried. The area of the first was equal to about 25 per cent. of the area of the vertical section of the flue. With a velocity of ten feet per second through the flue, the draft gage registered a drop of 0.42 inch W. G. through this orifice. This was considered excessive since the draft would undoubtedly be seriously affected by much added resistance. An orifice having an area of about 50 per cent. of the flue was then constructed. With this orifice, the drop under the same velocity was but 0.13 inch W. G. and at the lowest velocities was about 0.015 inch W. G. An orifice of this size was therefore adopted. The area of the orifice (26″ × 26″) was a little larger than one-half (55 per

cent.) the area of the flue. A sketch of the part of the flue containing the diaphragm is shown in Fig. 2.

In order to make the conditions more comparable to those actually found in flues leading from kiln to stack, the end of the flue was partly closed. The obstruction served as the resistance offered to the flow of the gases by the furnaces and kiln, and was made equal to about 0.2 inch W. G. under maximum velocity conditions. It has been found that, for ordinary round kilns, the draft gage reaches a maximum of about 0.2 inch W. G. The

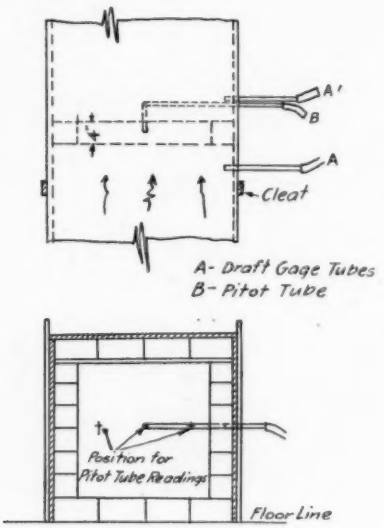

FIG. 2.—Portion of flue showing diaphragm and positions of tubes.

draft gage tube "A" (Fig. 2) between the diaphragm and the end of the flue would therefore register a pressure of 0.2 inch plus the resistance from the end of the flue to the tube, while the draft gage tube "A'" beyond the diaphragm would read this resistance plus the resistance offered by the diaphragm. These gage tubes were placed about three inches from the diaphragm on each side and entered the flue through holes in the center of one side. They projected about one inch into the flue but this distance is not important since the gage reading was not affected by any change.

Measurements.

A Pitot tube was used to measure the velocity of the gas through the orifice for every reading taken on the draft gage. The Pitot tube was practical in this case for we had a straight flow of gas and the velocity through the orifice—400 to 1000 feet per minute —was high enough to assure accuracy. The Pitot tube was inserted just behind the diaphragm (Fig. 2) and through the same opening used for the draft gage tube—the bent end of the Pitot tube reaching just to the center of the wall. The Pitot tube therefore gave the pressures existing in the orifice. Three readings were taken across the orifice, as marked in Fig. 2—the average of these being taken as the average pressure in the orifice.

An inclined manometer, which could be so adjusted that from two to forty inches of slant along the manometer was equivalent to one inch of vertical reading, was used. The forty-inch slope of the manometer assured an accurate reading with low velocities. In converting the manometer readings to inches of water gage, they were multiplied by the specific gravity of the oil used (0.837).

Since one part of the Pitot tube gives total pressure and the other static pressure, the difference being the velocity pressure, if each tube is connected to the ends of the manometer tube, the differential reading will be the velocity pressure. To illustrate, suppose a reading is 3.82 and the manometer is set at a slope of 20 (that is, 20 inches on the manometer being equivalent to one-inch vertical reading). Then $3.82 \div 20 = 0.191''$ vertical reading. Multiplying by 0.837, the specific gravity of the oil, $0.191 \times 0.837 = 0.16''$ W. G. = the velocity pressure. The velocity of the gas is then determined by means of the formula—

$$V = K\sqrt{p},$$

where V = velocity in feet per minute,
p = velocity pressure in inches W. G.,
and K = velocity constant.

The velocity constant K changes with the temperature. At 70° F. it is 4006. A table giving these constants is included later. The photograph (Fig. 1) shows the arrangement of the entire apparatus. The inclined manometer is shown directly above the word "Pitot."

Before making any tests, readings of the Pitot tube were checked against the tubes used with the draft gage for static pressure. The manometer was also checked against the draft gage. Each tube was inserted at the same time, the fan operated, and the following results were obtained:

Draft gage tube.....	On draft gage....	0.587 inch W. G.
	On manometer...	0.591 inch W. G.
Pitot tube (static pressure)....	On draft gage....	0.579 inch W. G.
	On manometer...	0.582 inch W. G.

The readings of the Pitot tube and draft gage tubes varied less than 0.01, differing but 0.008, and the manometer and draft gage differed but 0.004. This was quite satisfactory and gave us more confidence in the readings of the Pitot tube.

The Tests.

In making the tests, the velocity through the flue was varied—200 feet per minute being the minimum. By partly closing the outlet of the fan, any desired velocity could be obtained.

The results secured with the 35″ by 35″ flue and 26″ by 26″ orifice are tabulated as follows:

TABLE I.

Static pressure before diaphragm (Tube A′ in Fig. 2).	Differential reading (draft gage).	Manometer.	Slope.	Velocity through orifice in feet per minute.	Remarks.
0.02	0.017	0.4	40	370	Temperature 80° F.
0.048	0.04	1.00	40	587	Specific gravity of oil 0.837
0.065	0.052	1.30	40	668	Formula to figure velocity—
0.085	0.07	1.93	40	815	$V = K\sqrt{p}$.
0.12	0.10	2.45	40	917	K at 80° F. = 4044
0.13	0.107	2.57	40	938	Unrestricted outlet.
0.155	0.116	2.78	40	977	
0.17	0.12	2.90	40	995	
0.19	0.125	3.07	40	1030	

The size of the flue was next reduced to $23\frac{1}{2}$″ by $22\frac{1}{2}$″ (3.67 square feet). The area of the orifice was made 55 per cent. of that of the flue or 2.02 sq. ft. (17″ × 17″).

The results for a flue of this size are tabulated as follows:

TABLE 2.

Static pressure before diaphragm.	Differential reading.	Manometer.	Slope.	Velocity through orifice F. P. M.	Remarks.
0.02	0.015	0.18	20	351	Temperature 82° F.
0.027	0.022	0.29	20	446	K at 82° = 4050
0.034	0.028	0.33	20	476	
0.045	0.035	0.40	20	523	
0.057	0.048	0.55	20	614	
0.06	0.05	0.58	20	630	
0.09	0.062	0.88	20	776	
0.13	0.08	1.23	20	918	
0.15	0.11	1.30	20	945	
0.19	0.123	1.55	20	1030	

If the results secured by the use of the two orifices are compared, it will be found that they check very closely. For instance, for 370 feet per minute in the larger flue, a drop of 0.017 inch through the orifice was noted, while for 351 feet per minute in the smaller flue, we noted a drop of 0.015 inch. Again, with 1030 feet per minute in both flues, we noted 0.123 inch drop in one case and 0.125 inch in the other. This appears to indicate that if the ratio of the areas of orifices and flues are kept constant, the same drop in pressure through the orifice occurs with the same velocity—the size of the flue being unimportant.

The accuracy of the readings was tested by the use of the relation, "pressure or resistance varies as the square of the velocity." The average of the two tests was taken from the following condensed results (Table 3) giving only the drop in pressure through the orifice for the corresponding velocity. The higher velocities, 1100 to 1600 feet per minute, which the fan could not produce, were calculated from the pressure-velocity relation (Table 4). Under "ratio" is given the ratio of the first reading of pressure to every other pressure. The second ratio column gives the same for the velocities. Any pressure ratio should, therefore, be theoretically equal to the square of the corresponding velocity ratio.

TABLE 3.

Large flue.		Small flue.	
Pressure drop.	Velocity.	Pressure drop.	Velocity.
0.017	370	0.015	351
0.04	587	0.022	446
0.052	668	0.028	476
0.07	815	0.035	523
0.10	917	0.048	614
0.107	938	0.05	630
0.116	977	0.062	776
0.12	995	0.08	918
0.125	1030	0.11	945
0.150	1100	0.123	1030
0.178	1200	0.147	1100
0.210	1300	0.176	1200
0.243	1400	0.206	1300
0.279	1500	0.238	1400
0.318	1600	0.273	1500
...	..	0.312	1600

TABLE 4.—AVERAGE FOR TEMPERATURE OF 80° F.

Pressure drop.	Ratio.	Velocity through orifice.	Ratio.	Velocity through flue.
0.016	...	360	..	198
0.028	1.75	482	1.34	266
0.044	2.75	600	1.66	330
0.051	3.19	650	1.81	357
0.066	4.12	796	2.21	407
0.09	5.62	918	2.55	473
0.1107	6.92	952	2.64	523
0.115	7.19	970	2.69	533
0.124	7.75	1030	2.86	555
0.1485	9.29	1100	3.06	605
0.177	11.07	1200	3.34	660
0.208	13.0	1300	3.62	715
0.2405	15.03	1400	3.89	770
0.276	17.25	1500	4.17	825
0.315	19.68	1600	4.45	880

These ratios were plotted against each other and checked by drawing the theoretical pressure-velocity curves on the same chart (Fig. 3). With but two exceptions (the pressure drops of 0.066 inch and 0.09 inch) all points fall upon the curve. This appears to indicate that the drop in pressure through an orifice

is an accurate indication of the velocity of the air passing through a flue. The results were put in more convenient form by means of curves so that the velocities could be determined directly from the differential reading, providing the temperature is known

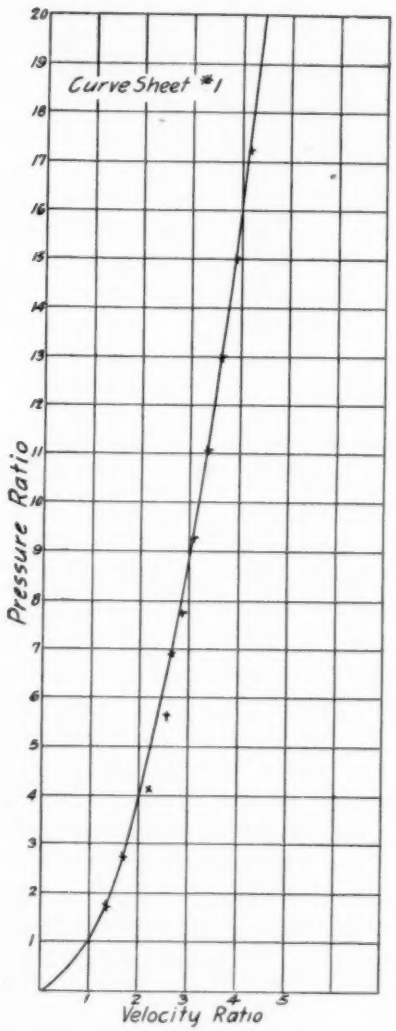

FIG. 3.

and the same ratio of orifice and flue, as used in this investigation, is employed.

The temperature of the gas is an important factor in the pressure developed at a certain velocity. It would appear that, as the temperature increases and the sp. gr. of the gas decreases, the pressure developed at a constant velocity becomes lower. Since the results (Table 4) were taken at a temperature of about 80° F., they cannot be applied to conditions in a flue, the temperature of which may be 1500° F. Results for the different temperatures must therefore be obtained.

A very simple method of converting the pressures from one temperature to that at another temperature was obtained by the use of the following "Table of Constants" (Table 5)[1] giving the velocity constants already mentioned for any temperature.

In Table 5, K represents the velocities of dry air, in feet per minute, required to sustain a column of water one inch in height. This was obtained by using the formula

$$k = \sqrt{\frac{2\,g \times \text{weight of 1 cu. ft. of water at 62° F.}}{12 \times \text{weight of 1 cu. ft. of air at temp. stated.}}}$$

Small k in the fomula is the velocity in feet per second and is multiplied by 60 to secure the values for K given in the table. g = acceleration due to gravity = 32.16.

The ratios given in the table are those between the fan speeds necessary for the various temperatures listed and 70° F. to produce the same water gage indication.

The table is used as follows: To change any pressure, say at 80° F. to that at 200° F. under the same velocity, divide the pressure at 80° F. by the square of the ratio of the velocity constant at 200° F. to the velocity constant at 80° F. For example, suppose we take the differential reading obtained for a velocity of 1600 feet per minute through the orifice or 880 feet per minute through the flue, which is 0.315 inch W. G. at 80° F., the temperature of the experiment. The ratio of the velocity constants at 200° F. and 80° F. would be $\frac{4470}{4044} \cdot \left(\frac{4470}{4044}\right)^2 = 1.22$ = the fac-

[1] This table was obtained from Mr. L. E. Eisensmith of the American Blower Co.

tor by which all pressures at 80° F. must be divided in order to obtain the pressure at 200° F. 0.315 ÷ 1.22 = 0.258. The pressure at 880 feet per minute at a temperature of 200° F. would therefore be 0.258 inch W. G.

TABLE 5.—CONSTANTS.

Figured for dry air at sea level.
Barometer 29.92 inches mercury.

Temperature.	K.	Ratio.	Temperature.	K.	Ratio.
40° F.	3567	0.890	480° F.	5332	1.331
30	3609	0.901	500	5389	1.345
20	3651	0.911	520	5445	1.359
10	3692	0.921	540	5500	1.373
0	3733	0.932	560	5555	1.387
10	3773	0.942	580	5609	1.400
20	3813	0.952	600	5663	1.413
30	3852	0.961	620	5716	1.426
40	3891	0.971	640	5769	1.439
50	3930	0.981	660	5821	1.452
60	3968	0.990	680	5873	1.465
70	4006	1.000	700	5925	1.478
80	4044	1.009	720	5976	1.491
90	4081	1.018	740	6027	1.504
100	4118	1.028	760	6077	1.517
110	4155	1.037	780	6127	1.530
120	4191	1.046	800	6177	1.542
130	4227	1.055	820	6226	1.554
140	4263	1.064	840	6275	1.566
150	4298	1.073	860	6323	1.578
160	4333	1.082	880	6371	1.590
170	4368	1.090	900	6418	1.602
180	4402	1.098	920	6465	1.614
190	4436	1.106	940	6512	1.626
200	4470	1.114	960	6558	1.638
220	4537	1.132	980	6604	1.649
240	4603	1.149	1000	6650	1.660
260	4668	1.165	1020	6695	1.671
280	4732	1.181	1040	6740	1.682
300	4796	1.197	1060	6785	1.693
320	4851	1.213	1080	6829	1.704
340	4921	1.228	1100	6873	1.715
360	4982	1.243	1120	6918	1.726
380	5042	1.258	1140	6962	1.737
400	5101	1.273	1160	7005	1.748
420	5159	1.288	1180	7048	1.759
440	5217	1.303	1200	7090	1.770
460	5275	1.317	..	..	...

In this way the pressures at 80° F. were converted into those at temperatures up to 1500° F. The results for each temperature were plotted as shown in Fig. 4. In plotting, the two velocities corresponding to the two points which were off the pressure-velocity curve were corrected in order to make the final curves

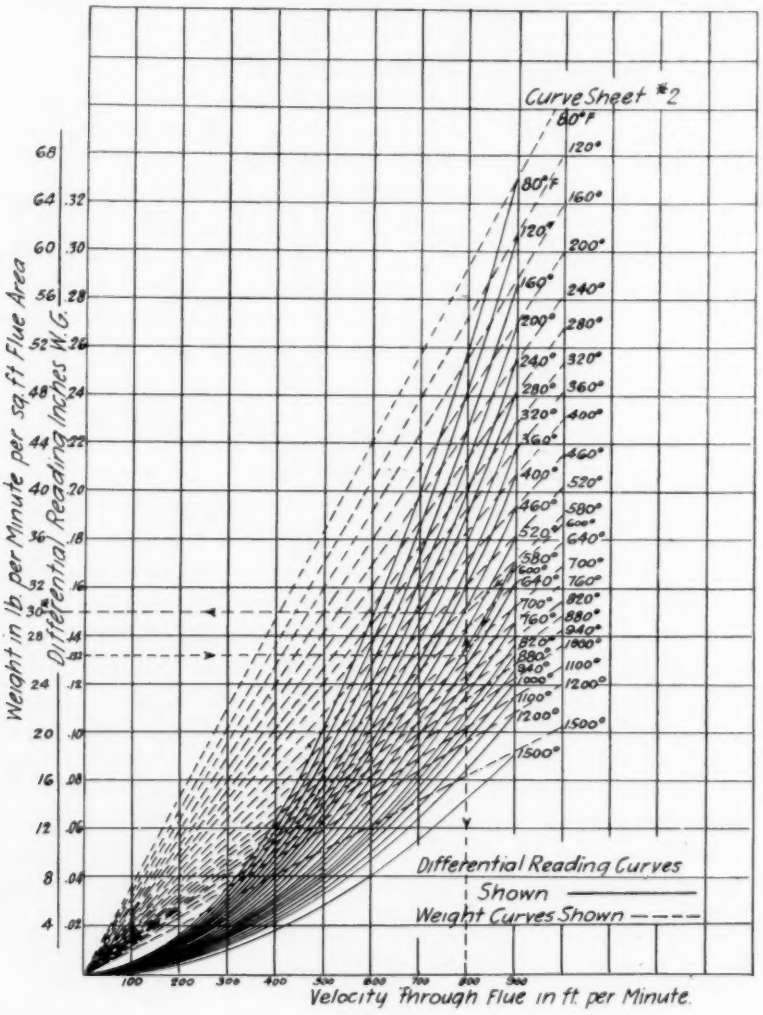

FIG. 4.

more accurate. From these curves, the velocity through the flue at any temperature can be secured from the differential draft gage reading. However, even the velocities may become misleading, since the same velocity at different temperatures does not mean the same weight of gases, and the weight of the gases after all is what we must have in order to determine the rate of combustion we are getting in the fire boxes. A set of velocity weight curves for the different temperatures was therefore drawn directly over the differential draft gage reading curves, and from this double set of curves the weight of the gas may be determined directly from the differential reading on the draft gage. This weight is expressed in pounds per minute per square foot of flue area—since this forms a basis from which the actual weight of gas can be figured for any flue. The weights are based on dry air—since the data in the "Table of Constants" was figured on the same basis. A source of error is introduced here since the weight of the air varies as the relative changes in humidity. However, the most useful part of these curves is from about 300° F. and higher. The relative humidity must become very low as the temperature increases beyond this point and the error should not be great enough to make the results unreliable.

An illustration of the use of the curves is indicated in Fig. 4. Assume a reading of 0.132 inch W. G. at a temperature of 600° F. in the flue. Approximating 600° F. on the solid line curves, we come down until we strike 0.132 on the differential reading scale. If we wish to determine the velocity, we drop to the abscissa and find it to be 800 feet per minute. To get the weight we proceed vertically in the direction of the arrow until we strike the approximate 600° F. curve on the broken line set of weight curves. We then go to the left to the weight scale along the ordinate and find it to be 30.

Conclusions.

Lack of time prevented any additional work. Since the differential readings at the higher temperatures are not very large, it would be interesting to run similar tests with a somewhat smaller orifice in order to determine the relation between the size of the orifice and the differential readings. It is very doubtful whether the orifice should be made smaller since the size used

produced a static pressure drop of somewhat over 0.1 inch W. G. The addition of 0.1 inch W. G. of static pressure to a stack would very likely push it to its limit in order to maintain sufficient velocity pressure to produce the desired draft movement.

It is interesting to note that, with induced draft, the static pressure gives a higher reading than the total pressure. The relation—"total pressure minus static pressure equals velocity pressure"—still holds, however, since in induced draft they are both negative and by subtracting the static from the total pressure we get a positive velocity pressure which is as it should be. For example, it we have a total pressure of 0.4 inch W. G. and a static pressure of 0.6 inch W. G.,

$$\text{then T. P.} - \text{S. P.} = \text{V. P.}$$
$$-0.4 - (-0.6) = +0.2.$$

With this, a possible method of using the draft gage to measure velocities and weights in a flue has been found. However, the work is merely experimental and should be tried out under actual conditions in order to determine its practicability. It shows possibilities and might, with some alterations, be of value in the firing of kilns. Conditions vary at every plant, but there seems to be no reason why any one plant could not prepare a set of readings by this method for use in noting whether or not the burn is progressing satisfactorily.

DISCUSSION.

MR. DAVENPORT: I would like to ask Mr. Harrop whether the minimum static pressure observed in these tests was comparable with the minimum observed in ordinary kiln firing. Although the data presented is interesting from the theoretical standpoint, it has been my experience that the very low draft pressures involved in periodic kiln firing render it exceedingly difficult to secure reliable readings. Mechanical engineers have about given up the problem of trying to read pressure differences amounting to only 0.04″ to 0.05″ of water.

MR. HARROP: Our method of measuring the pressure involved the use of a manometer similar to that used by the American

Blower Company. This manometer may be set at a very low angle and is very sensitive. I realize that it is very difficult to secure an accurate reading in this way, but to my knowledge this manometer is the most delicate instrument available for use in measuring the velocity pressure by the Pitot tube method. In regard to the pressures employed, the static pressure resulting from the resistance through a kiln at the beginning of a burn was taken as 0.02″ and was determined by an actual kiln reading. This static pressure of 0.02″ resulted from the resistance of the kiln to the flow of gases. In other words, that static pressure would have shown up on the kiln side of the diaphragm. As the burn continued the static pressure increased to about 0.21″ at the highest temperature.

MR. DAVENPORT: I would like to add that this problem of the determination of the amount of air or gas moving through kilns is an important one, but I would also like to emphasize the fact that it it a complex one and one which has for some time baffled the best efforts of mechanical engineers. The Thomas Electric meter seems to offer one practically reliable method of determining the flow of gases at very low velocity pressures; but in my own experience with Pitot tubes I have found, inasmuch as the variation may be as much as 50 per cent. plus or minus, that an endeavor to reduce the results to absolute values below about 0.05″ is fruitless. I believe, however, that if work of this kind were undertaken by ceramic engineers and an active demand were created for some means of measuring very low draft pressures, that some good would come of it; but at present the Pitot tube and slant gage are conceded by most authorities to be exceedingly unsatisfactory for the measurement of low velocities.

COMMUNICATED DISCUSSIONS.

ELLIS LOVEJOY: Mr. Fritz has given us a very creditable piece of work and it is to be hoped that it will lead to some improvement in the important burning operations.

I have had no respect for a draft gage for some time and the majority of clay workers are also lacking in respect—if I may judge from the number of gages I have seen entirely out of com-

mission, or running their course of uselessness without any attention. Where records are kept, the firemen have settled down to filling in the spaces in a prefunctory manner without even reading the gages and the data slips are added to the dusty pile in the corner of the kiln house.

A draft gage attached to a chambered continuous kiln compartment will show several tenths minus pressure in the early stages of the compartment's operation. As the fires approach the compartment in question, the pressure will drop back to zero and often go beyond, indicating no draft, in fact a back pressure, yet the operation of the kiln moves along in spite of the readings of the draft gage. The behavior is easily explained and the explanation condemns the draft gage.

A differential gage will, as Mr. Fritz has shown, give us correct draft readings which may be reduced to velocity and to volume of gas moved. The attachment of such a gage to a kiln is a problem in itself.

Consider the chambered continuous kiln for example. The natural location for the gage would be in the long flue connecting the kiln to the stack or fan, but in the modern kiln there are two distinct operations carried on by the fan draft; namely, burning and water-smoking, each under damper control. Draft gage readings beyond these dampers would be of no value and there is no room between the dampers and the kiln as a rule. It would be impracticable to make the connections on opposite sides of the chamber division walls because of the wide difference in temperature.

Down-draft kilns may have wall stacks, outside stacks in close proximity to the kiln, or distant stack or fan. In the first two instances the differential gage could only be attached to the stack with such adjustments as may be necessary for the difference in altitude. The stack, and this is also true of any flue, must be large enough to accommodate a suitable diaphragm having an opening of requisite size for the kiln operation and there will be an essential difference in temperature for which correction must be made.

Besides the difference in temperature on opposite sides of the diaphragm, we must take into consideration the constantly ad-

vancing temperature in the kiln flue and stack, and we must also consider that the stack and flue temperatures, will vary widely at any given stage in successive burns, and it is not safe to assume that, if on the sixth day of one burn we have 0.3 inch water gage draft, this will be the proper draft for the sixth day of any other burn.

The draft gage to be useful to the clay workers is not to tell them what has been done but to direct the work in the future. Its real purpose is to enable the manager to put in the kiln house a diagram showing the burner just what the draft gage should read at every stage in the process to the end of the burn.

How far the draft gage may become useful in kiln operations remains to be seen, but it will, in kiln tests under competent handling, determine proper kiln pressures for various wares in several types of kilns and thus give us the necessary data for better kiln design and construction.

Mr. Fritz states that for ordinary round kilns the draft reaches a maximum of about 0.2 inch water gage.

I have been seeking this data for some time and if he has accurate records along this line I should very much like to have them. Down draft kilns vary widely in the construction of the floor flue system and there is a greater variation in the kiln setting.

A gas burning kiln with a simple floor system set with drain tile or other hollow ware is a very different matter from a closely set face brick kiln with a complicated floor flue system, burned with coal fired in grate bar furnace.

It seems to me that 0.2 inch water gage is too low for a maximum resistance in down draft kilns, and I am inclined not to accept it without further proofs of actual tests under maximum resistance conditions.

C. B. HARROP: Regarding the statement in the impromptu discussion offered by Mr. Davenport, relative to the impracticability of Pitot tube readings under low pressure conditions, attention should be called to two points: First, as the diaphragm orifice (where the Pitot tube was placed) was approximately 50 per cent. of the area of the flue, the velocity through the orifice

was approximately double that through the flue. This gave at all times sufficient velocities to be satisfactorily read with the Pitot tube. Second (as shown in Fig. 3), the relation between velocities determined by the Pitot tube and resistance or pressure drop results in practically a perfect "R varies as V^2" curve, which in itself proves that the Pitot tube readings were amply accurate for the work.

THE CLAYS OF FLORIDA.

By E. H. Sellards.

The clays of Florida that are being utilized include those from which building brick and tile are made, the white-burning ball clays or plastic kaolins, and fuller's earth. The production of building brick during 1916 amounted to 31,129 million, the value of which, including a small amount of tile and fire-proofing brick, was $226,362. The production of plastic kaolin is limited at the present time to the output of three plants under the management of two companies. During 1916 five plants were engaged in mining fullers' earth, the production from these five plants being about 90 per cent. of the total production of this material in the United States.

In their geologic relation the clays of Florida all lie above the Oligocene limestones since beneath these formations are Eocene limestones which, at least in the peninsular section of the State, extend uninterruptedly to a great depth.

The fuller's earth clays lie within the Alum Bluff formation which, according to the vertebrate fauna obtained within recent years, is Miocene. The clays used in brick making vary in age probably from the Miocene to the Pleistocene or Recent. The geographic distribution of the clays likewise is irregular, although all that are being utilized are found in the northern part of the State—within 200 miles or less of the north line.

The Florida Common Clays.

No clays suitable for making vitrified brick have been located within the State. In 1915 a series of tests of 25 samples of Florida clays was made by the Bureau of Standards laboratory at Pittsburgh. The clay samples for these tests were collected by the Florida Geological Survey. The 25 samples tested represented clays from 21 counties in Florida. Each sample approximated 250 pounds in weight and was representative, as nearly as could

be judged, of the clay of the locality from which it was taken. These tests were not successful in locating any clays that would serve in the manufacture of vitrified brick. Although previously published in the reports of the Florida Geological Survey, the results from a few of these 25 tests on the common clays of Florida may be here included for convenience of reference.

Sample No. 1, Jackson County.—The clay works with some difficulty in the stiff-mud condition; water of plasticity in per cent. of dry weight, 40.80 per cent.; warped and cracked during the drying treatment; linear drying shrinkage, in terms of wet length, 9.95 per cent.; linear burning shrinkage in terms of dry length, at 850° C., 0.77 per cent.; at 1010 ° C., 4.59 per cent.; at 1130° C., 6.60 per cent.; at 1250° C., 7.55 per cent.; color after burning, light red at lower temperatures, changing to dark red at higher; per cent. porosity, at 850° C., 36.75 per cent.; at 950° C., 40.55 per cent.; at 980° C., 34.30 per cent.; at 1010° C., 30.30 per cent.; at 1040° C., 24.20 per cent.; at 1070° C., 24.00 per cent.; at 1100° C., 26.10 per cent.; at 1130° C., 25.15 per cent.; at 1160° C., 23.65 per cent.; at 1190° C., 23.60 per cent.; at 1220° C., 23.85 per cent.; at 1250° C., 20.70 per cent. A somewhat plastic and sticky clay of high drying and burning shrinkage. The clay retains a porous structure at 1250° C., and cannot be used in the manufacture of vitrified ware burned in commercial kilns. The clay may be used in the manufacture of common and building brick.

Sample No. 2, Washington County.—The clay possesses good working plasticity and molding behavior; water of plasticity, 36.0 per cent.; a few cracks developed by drying; linear drying shrinkage, 9.42 per cent.; linear burning shrinkage, at 850° C., 0.55 per cent.; at 1010° C., 1.57 per cent.; at 1130° C., 7.75 per cent.; at 1250° C., 8.10 per cent. A good light buff color is developed by burning; per cent. porosity, at 850° C., 36.80 per cent.; at 950° C., 35.30 per cent.; at 980° C., 34.75 per cent.; at 1010° C., 34.50 per cent.; at 1040° C., 30.75 per cent.; at 1070° C., 25.70 per cent.; at 1100° C., 22.45 per cent.; at 1130° C., 19.70 per cent.; at 1160° C., 17.95 per cent.; at 1190° C., 15.70 per cent.; at 1220° C., 14.60 per cent.; at 1250° C., 12.55 per cent. A buff burning clay of good plasticity and a relatively high drying shrinkage.

May be used in the manufacture of buff colored face brick, although care must be exercised in drying. The clay must be burned above 1250° C. in order to attain low porosity.

Sample No. 3, Santa Rosa County.—The clay has good working plasticity and molding properties; water of plasticity, 28.90 per cent.; no drying difficulties; linear drying shrinkage, 6 per cent.; linear burning shrinkage, at 850° C., 0.64 per cent.; at 1010° C., 0.21 per cent.; at 1130° C., 1.44 per cent.; at 1250° C., 1.17 per cent.; burns to salmon color, changing to buff at higher temperature; per cent. porosity, at 850° C., 35.30 per cent.; at 950° C., 35.80 per cent.; at 980° C., 36.20 per cent.; at 1010° C., 34.86 per cent.; at 1040° C., 33.60 per cent.; at 1070° C., 32.15 per cent.; at 1100° C., 31.10 per cent.; at 1130° C., 29.55 per cent.; at 1160° C., 29.05 per cent.; at 1190° C., 28.80 per cent.; at 1220° C., 28.05 per cent.; at 1250° C., 27.30 per cent. A clay possessing good working and drying qualities but which cannot be vitrified at the burning temperatures of commercial kilns. Test pieces burned to 1250° C. are easily cut by a knife. This clay is of value only in the manufacture of porous common building brick, etc.

Sample No. 4, Escambia County.—Appears to have good working behavior and plasticity; water of plasticity, 21.95 per cent.; drying behavior satisfactory; linear drying shrinkage, 5.75 per cent.; linear burning shrinkage, at 850° C., 1.28 per cent.; at 1010° C., 0.05 per cent.; at 1130° C., 0.26 per cent.; at 1250° C., 1.16 per cent.; color after burning, light to dark red; per cent. porosity, at 850° C., 28.65 per cent.; at 950° C., 29.30 per cent.; at 980° C., 28.20 per cent.; at 1010° C., 27.90 per cent.; at 1040° C., 27.75 per cent.; at 1070° C., 25.85 per cent.; at 1100° C., 26.95 per cent.; at 1130° C., 25.70 per cent.; at 1160° C., 27.95 per cent.; at 1190° C., 26.80 per cent.; at 1220° C., 19.90 per cent.; at 1250° C., 20.20 per cent. A clay possessing good working and drying behavior, but one which retains a porous structure at temperatures as high as 1250° C. The clay is suitable for common and face brick, etc., but not for paving brick or other vitrified ware.

Sample No. 5, Walton County.—Plasticity and working properties good; water of plasticity, 28.30 per cent.; drying behavior

satisfactory; linear drying shrinkage, 6.75 per cent.; linear burning shrinakge, at 850° C., 0.34 per cent.; at 1010° C., 0.35 per cent.; at 1130° C., 2.17 per cent.; at 1250° C., 2.25 per cent.; color after burning, salmon to light red; per cent. porositv, at 850°, C., 33.60 per cent.; at 950° C., 33.20 per cent.; at 980° C., 35.40 per cent.; at 1010° C., 34.35 per cent.; at 1040° C., 32.80 per cent.; at 1070° C., 30.50 per cent.; at 1100° C., 29.85 per cent.; at 1130° C., 28.60 per cent.; at 1160° C., 27.55 per cent.; at 1190° C., 27.80 per cent.; at 1220° C., 27.10 per cent.; at 1250° C., 26.00 per cent. A red burning clay having good working and drying behavior, but retaining a porous structure. Test pieces burned to 1250° C. are easily scratched by a knife. This clay is suitable for the manufacture of porous common and building brick. Not practical to vitrify in commercial kilns.

Sample No. 11, Duval County.—Fairly plastic, fairly good working qualities; water of plasticity, 27.4 per cent.; dries satisfactorily; linear drying shrinkage, 9.6 per cent.; linear burning shrinkage, at 990° C., 0.05 per cent.; at 1110° C., 0.82 per cent.; at 1230° C., 2.34 per cent.; at 1320° C., 3.97 per cent.; red burning; per cent. porosity, at 850° C., 28.1 per cent.; at 950° C., 26.8 per cent.; at 980° C., 25.7 per cent.; at 1010° C., 25.8 per cent.; at 1040° C., 24.8 per cent.; at 1070° C., 24.6 per cent.; at 1100° C., 22.5 per cent.; at 1130° C., 22.5 per cent.; at 1160° C., 20.4 per cent.; at 1190° C., 16.6 per cent.; at 1220° C., 11.5 per cent.; at 1250° C., 7.5 per cent. A sandy surface clay of fair working and drying behavior. A decrease in porosity is noted with increase in temperature, although it is doubtful whether a vitrified product may be manufactured from this material, owing to the relatively high temperatures necessary.

Sample No. 12, Clay County.—Very plastic, and possesses fair working qualities; water of plasticity, 34.4 per cent.; excessive drying shrinkage; linear drying shrinkage, 12.22 per cent.; linear burning shrinkage, at 990° C., 1.45 per cent.; at 1110° C., 3.48 per cent.; at 1230° C., 4.87 per cent.; red burning; per cent. porosity, at 850° C., 24.4 per cent.; at 950° C., 22.7 per cent.; at 980° C., 19.6 per cent.; at 1010° C., 18.7 per cent.; at 1040° C., 18.7 per cent.; at 1070° C., 17.4 per cent.; at 1100° C., 17.3 per cent.; at 1130° C., 16.8 per cent.; at 1160° C., 16.9 per cent., at 1190° C.,

16.0 per cent.; at 1220° C., 14.4 per cent.; at 1250° C., 13.8 per cent. A plastic red burning clay having a high drying shrinkage. Care must be exercised in drying heavy pieces. This clay has a relatively low porosity at commercial kiln temperatures and attains a fairly dense structure.

Sample No. 21, Jefferson County.—Medium plastic with fair working properties; water of plasticity, 32.6 per cent.; no drying difficulties; linear drying shrinkage, 9.77 per cent.; linear burning shrinkage, at 990° C., 0.22 per cent.; at 1110° C., 1.09 per cent.; at 1230° C., 0.55 per cent.; at 1320° C., 0.49 per cent.; buff burning; per cent. porosity, at 990° C., 35.6 per cent.; at 1020° C., 34.0 per cent.; at 1050° C., 33.2 per cent.; at 1080° C., 33.4 per cent.; at 1110° C., 33.8 per cent.; at 1140° C., 33.6 per cent.; at 1170° C., 33.6 per cent.; at 1200° C., 33.7 per cent.; at 1230° C., 32.8 per cent.; at 1260° C., 34.4 per cent.; at 1290° C., 33.7 per cent.; at 1320° C., 33.5 per cent. A sandy buff burning clay which retains an open porous structure at temperatures up to 1320° C. May have some use in the manufacture of soft porous common building brick.

Sample No. 22, Polk County.—Medium plastic with fair working properties; water of plasticity, 24.9 per cent.; no drying difficulties; linear drying shrinkage, 6.28 per cent.; linear burning shrinkage, at 950° C., 0.37 per cent.; at 1100° C., 0.47 per cent.; at 1220° C., 0.08 per cent.; at 1310° C., 0.24 per cent.; burns red; per cent. porosity, at 950° C., 35.6 per cent.; at 1010° C., 35.8 per cent.; at 1040° C., 35.6 per cent.; at 1070° C., 36.0 per cent.; at 1100° C., 34.8 per cent.; at 1130° C., 33.8 per cent.; at 1160° C., 33.8 per cent.; at 1190° C., 33.7 per cent.; at 1220° C., 33.6 per cent.; at 1250° C., 33.7 per cent.; at 1280° C., 33.4 per cent.; at 1310° C., 33.6 per cent. A sandy red burning material which retains an open porous structure at temperatures up to 1320° C. May have some use in the manufacture of soft porous common building brick.

The Florida Plastic Kaolins.

Occurrence.—The plastic kaolins of Florida present problems of exceptional interest. The formation which holds the clays is

probably co-extensive or nearly so with the physiographic type known as the Lake Region of Florida. This belt of country extends in the peninsula of Florida from Clay County on the north to near the middle of DeSoto County on the south, a distance of about 150 miles. In width the belt varies from 10 to 30 or 40 miles. Small lakes are numerous. Their basins, as a rule, are circular in outline and relatively deep with steep sides. The uplands are sandy and well drained. A similar type of topography, underlaid probably by the same formation, is found in several counties in west Florida between the Suwanee and Choctawhatchee rivers.

The clay in this formation is intimately associated with coarse sand from which it is removed by washing. Mica is also present and is removed by screening. The sand in this formation is usually coarse and in places affords the sharpest and best building sand found in Florida.

The place of the clay-bearing formation in the geologic time scale is difficult to determine owing to the complete absence of fossils. It overlies the Oligocene limestones. There is also some reason for believing that it lies at a stratigraphic level higher than the fuller's earth beds and hence is not older than the Miocene. However, inasmuch as no one of the later fossiliferous formations is found overlying this formation, it has not been possible to fix its age more definitely.

The two localities at which this clay is being worked are Edgar in Putnam County and Okahumpka in Lake County. At Edgar, 4 to 10 feet of loose sand lies above the kaolin-bearing sand. This top sand is coarse—containing silicious pebbles up to one-third of an inch across. The large pebbles are flattened and all are rounded. The kaolin-bearing sands beneath are gray in color, although the weathered surface is sometimes slightly iron-stained. They are said to have a total thickness of 30 feet or more and are underlaid by a sticky, blue clay. It is reported that beneath the blue clay a fuller's earth occurs, and that this in turn passes at a depth of about 70 feet into a scarcely indurated shell stratum. A well put down by the Edgar Plastic Kaolin Company is reported to have passed through coarse superficial sand, 10 feet; kaolin-bearing sands, 30 or more feet; sticky, blue clay with fuller's

earth beneath, about 40 feet; scarcely indurated shell stratum, 20 feet. The well terminated on a hard limestone at the depth of 90 feet, probably the Chattahoochee limestone, which is Upper Oligocene in age, or possibly the Eocene limestones which lie next beneath—the Chattahoochee formation being usually wanting along the eastern slope of the peninsula.

The kaolin in Lake County occurs under conditions similar to those found in Putnam County. The superficial sands here, as at the Edgar mines, are coarse and contain white, silicious pebbles. The kaolin-bearing sands are gray in color except where stained red with iron. A small amount of mica, found in the kaolin sands, is screened out in the process of washing.

The sand-clay mixture of this formation is often well adapted to road construction, and is frequently so used, especially when somewhat colored by iron-staining as it often is near the surface.

The Florida kaolin-bearing formation is plainly sedimentary in origin and represents, as indicated by the rather coarse sand, a relatively near-shore accumulation of material. The association of the finely divided clay with the coarse quartz sand and the mica is one of the problems of this formation.

Mining.—In mining the Florida kaolin the overburden, which consists of a few feet of sand or iron-stained sand and clay, is removed—usually by the hydraulic process. The clay itself is lifted chiefly by suction pumps which are carried on a floating dredge. The pits are first of all opened to the water table level, which lies at a moderate although varying depth, depending upon the topography. The dredges are then floated on the water that accumulates in the pit. The dredge itself carries a relay station. On some of the dredges this relay pumping station, corresponding to the sump-hole of ordinary hydraulicing, is itself submerged. The pump removing the clay from the sump-hole has a capacity slightly greater than the pump which brings the clay to the sump-hole. Thus, notwithstanding the fact that the process goes on just below the surface of the water, no part of the clay is lost at the relay station because all that goes into the bin is removed at once—the suction of the pump preventing the escape of the floating particles of clay.

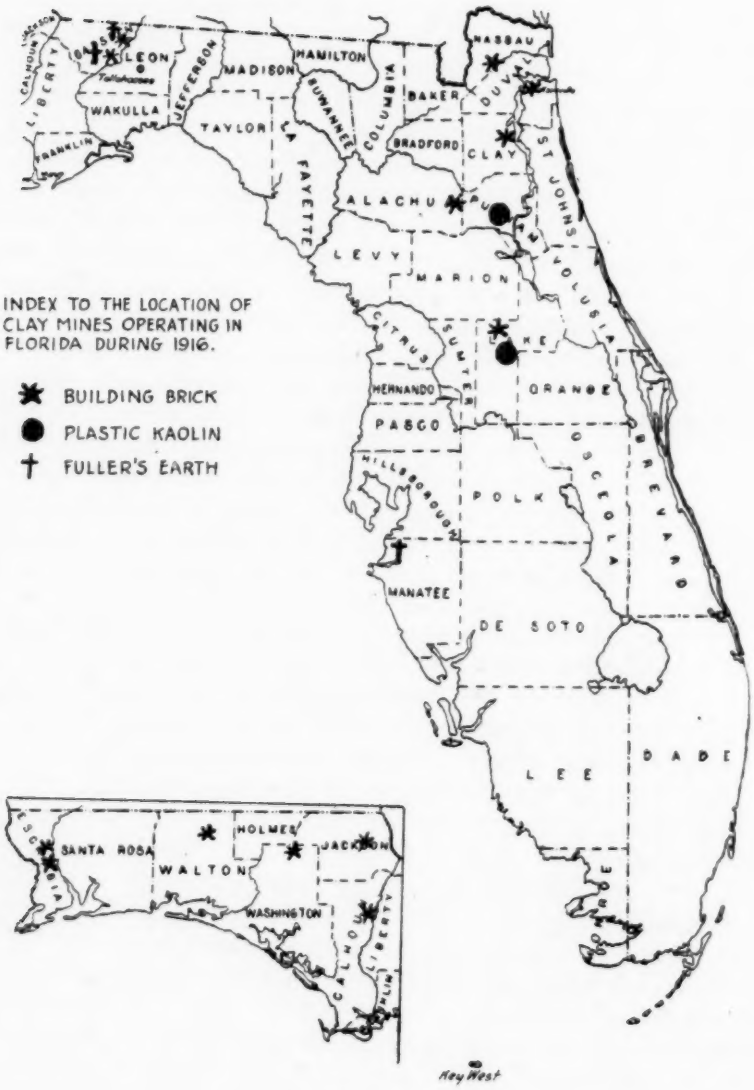
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FIG. 1.

From the relay pumping station on the dredge the material passes through the washing station where the coarse sand and clay balls are removed to settling tanks. From the settling tanks the clay is again pumped into compressors. After the excess of moisture is removed by compression, the clay is further artificially dried for shipment.

All of the plastic kaolin produced in Florida is shipped out of the State and is used chiefly or entirely in mixing with other clays where it is of value because of being plastic as well as white burning and refractory. Chemical analyses of this clay have been previously published and are accessible. On the map, which accompanies this paper, is indicated the location of the plants in Florida which are producing this clay, and also the location of the brick clay and fuller's earth plants of the state. The bibliography which follows includes references to some of the relatively few papers that have been published on the Florida clays.

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FLORIDA STATE GEOLOGICAL SURVEY.

AN ATTEMPTED HEAT BALANCE OF A CONTINUOUS KILN OF THE CHAMBER TYPE.

By C. Treischel and H. S. Robertson, Schenectady, N. Y.

The available ceramic literature at the present time shows a great scarcity of heat-balance data. The relatively long test periods necessary in securing authentic results has tended toward discouraging the collection of such data, the value of which has long been recognized. It is with the idea of "helping along the cause" which has been sustained by Bleininger,[1] Gelstharp[2] and Harrop,[3] that the authors have decided to present this data to the Society. The tests were conducted on one of the kilns at the Alton plant of the Alton Brick Company, Alton, Ill.

The Kiln.—The kiln was of the chamber, moving fire type, having fourteen chambers arranged in one continuous row. Each chamber received its fire from one side only, working on the down-draft principle, the flames coming up over a bag-wall, spreading over the chamber and passing out through the floor. That half of the floor nearest the bag-wall was closed, the other half was open, thus providing for a good distribution of heat over the entire chamber. A connecting flue for carrying the hot combustion gases from chamber to chamber extended the full length of the kiln beneath the floor level. The waste combustion gases and waste water-smoking gases were led from each chamber by auxiliary flues which connected with the main waste-gas and main water-smoking flues through bell dampers, all being underground. These main flues were parallel with the kiln and each was provided with a fan for creating draft.

Water-smoking was accomplished by drawing the gases from the cooling chambers behind the fires through a sheet-steel flue supported about ten feet above the top of the kiln. (This is known

[1] *Trans. Am. Ceram. Soc.*, **10**, 412 (1908); **11**, 153 (1909).

[2] *Ibid.*, **12**, 621 (1910).

[3] *Ibid.*, **19**, 216 (1917); This Journal, **1**, 35.

as the short-circuiting flue.) The gases pass down through the chambers which are water-smoking and out into the main water-smoking flue.

The fuel used, producer gas, was supplied through a large main flue extending the full length of the kiln, below the floor level and on the opposite side from the main water-smoking and main waste-gas flues. Distributing flues, one for each chamber, rose perpendicularly to the top of the kiln, at which point each led off at right angles into a horizontal flue which extended across the kiln, parallel to the axis of the chambers. These horizontal flues were integral with the kiln brick work and placed between the chambers. The gas was then delivered by small ducts to the foot of the bag-walls.

The Gas Producers.—The gas producers were in two batteries of four each, being of the simple or carbon-monoxide type. They were rectangular in plan with a single hopper at the top for feeding the coal. Two holes were provided in the side walls, through which a poker could be thrust for stirring up the fuel bed. No seal was used, the coals resting on horizontal grates at the bottom. The firing interval was fifteen minutes and the grates were cleaned every eight hours.

The Ware.—The wares burned were shale paving block and hard burned shale building brick, both maturing at about cone 4, or, to be exact, 1120° C. The pavers were wire-lug-cut and the builders were side-cut. The percentage of No. 1 ware produced was high, showing a good distribution of heat from top to bottom.

Testing Apparatus Used.

(*a*) **Gas Testing Apparatus.**—This consisted of a Burrell complete gas analysis outfit of the portable type, provided with pipettes for the determination of CO_2, CO, O_2, and unsaturated hydrocarbons by absorption and H_2 and CH_4 by combustion. Both the flue-gas and producer-gas were analyzed with this outfit.

(*b*) **Junker's Gas Calorimeter.**—It was planned to use this apparatus in obtaining the heating value of the producer-gas, but owing to adverse conditions the results could only be used as checks, the heating value being obtained by calculation.

(*c*) **Thermocouples.**—A noble metal couple was used for high temperature work and two base metal couples for obtaining the temperatures in the producer-gas and waste combustion-gas flues.

(*d*) **Gas Collecting Apparatus.**—In order to obtain true gas samples from the various flues and the interior of the burning chambers, pieces of $^3/_4''$ iron pipe were used. These varied in length from 6 to 9 feet, were closed at one end and bushed down at the other to take a 12-in. length of $^1/_4''$ pipe. Holes were drilled at random along the length of the $^3/_4''$ pipe, those nearest the bottom being larger than the ones at the top. The gas sample was drawn through these tubes into a large pressure tank. This pressure tank was designed similar to the large tanks used by gas companies. Its cubic capacity was about $2^1/_4$ cubic feet. In operation, the lower half was filled with water which had been saturated with the gas to be sampled. The upper half was then placed in position and lowered until the water started to flow from the intake pipe in its head. The tank was then connected to the sampling tube by a long piece of rubber hose. Then by raising the upper half of the tank a vacuum was created, the water forming a seal, and the gas flowing into the tank. By emptying and refilling the tank two or three times, a sufficiently pure sample was obtained. Then, if it was desired to use the Junker calorimeter for obtaining the heating value of the gas, all that was necessary was to connect the full tank to the calorimeter, the weight of the upper half of the tank being sufficient to maintain the proper pressure.

(*e*) **Thermometers.**—A centigrade thermometer was used in obtaining the temperature of the gas in the waste water-smoking flue and of the atmosphere. Wet- and dry-bulb thermometers were not used for obtaining the humidity of the air, as the test was carried on during a rain-storm and heavy mist, so that the relative humidity was 100 per cent.

The Heat Balance.

In making a heat balance on a producer-gas fired continuous kiln the following factors must be determined:

A. Heat introduced as fuel.
B. Heat lost by un-burned carbon in ashes.
C. Heat lost in the producer.
D. Heat used in the burning of the ware.
E. Heat lost in the combustion-gases.
F. Heat lost in water-smoking gases.
G. Heat taken up by the kiln and lost by radiation.

In order to obtain the data for the above factors the following observations, analyses, etc., were made:

Methods Used in Obtaining Data.

1. Tons of Coal Used.—The weight of coal required to charge the hopper of the producer to each of three different depths was determined and subsequent charges were noted as $^1/_4$, $^1/_2$ and full hoppers. In each case the depth of charge was determined by measurement and recorded on a firing sheet. This process was continued for a complete cycle of the kiln, which covered a period of four hundred and seventy-eight hours. Knowing the weight of coal corresponding to each of the three depths, the total amount of coal used during the period was calculated.

This method must necessarily depend upon the intelligence of the firemen and the interest which they take in the work. Small errors will be of a compensating nature, so that large errors need only be guarded against.

2 and 3. Heating Value and Analysis of Coal.—An average sample of the coal was taken over a period of seventy-two hours. Each time the fireman fired his producer he threw a small quantity of coal on a pile. At the end of the period this pile was quartered to a small pile and gathered in a sampling can. This sample was analyzed by the Department of Applied Chemistry of the University of Illinois under the direction of Mr. J. M. Lindgren.

4. Analysis of Producer Ashes.—Each time the fireman cleaned the grates, he threw a small quantity of ashes onto a pile. This pile was quartered down and the sample gathered in a sampling can. This sample was also analyzed by the Department of Applied Chemistry, Univ. of Ill.

5 and 6. Analysis of Producer-Gas and Flue-Gas.—These analyses were made with a Burrell apparatus.

7. Temperatures of Gases in Producer-Gas and Waste-Gas Tunnels.—A base-metal thermocouple was inserted into the flue through an opening in the top and readings taken in millivolts with a portable Leeds and Northrup potentiometer equipped with compensation coils for the temperature correction of the cold junction of the thermocouple. The thermocouples were calibrated and the millivolt readings were transferred to temperature readings by interpolation from the calibration curves.

8. Maximum Burning Temperature.—A platinum-platinum rhodium thermocouple was inserted through the crown into the chamber on high fire. Readings were taken with a potentiometer.

9. Humidity of the Air.—As stated before, the relative humidity was 100 per cent., due to the fact that rain and heavy mist fell throughout the test.

10. Humidity of Waste Gases.—Due to the inaccessibility of the top of the waste-gas stack and the large volume of sulphur-gases coming from the stack, this determination was neglected.

11. Tons of Clay Burned.—The number of bricks or blocks set in each chamber was obtained from records in the company office. Ten blocks and ten bricks were weighed, to determine the average weight of each burned block or brick. From these weights and the number of blocks or bricks set in the kiln the tonnage of the kiln for the entire cycle was calculated.

12. Heating Value with Junker's Calorimeter.—This method is a direct method for obtaining the heating value of a gas. A known volume of gas is burned and allowed to heat a known weight of water, the temperature rise in the water being observed. From this data the heating value is calculated. Due to the fact that conditions were not favorable for the accurate working of the calorimeter—there being drafts blowing over the work-table, and a variable gas supply—these results were used only as a check, the calculated heat value being used throughout the work.

Method of Calculation.

The method of calculation employed followed the general method set down by Bleininger, Gelstharp and Kratz.[1] In specific cases the method was altered to suit the conditions of the data used.

The items to be calculated in the determination of the factors necessary for a complete heat balance such as this are:

A. Heat Introduced as Fuel.
   1. Number of pounds of coal fired per ton of burned clay.
   2. Number of B. t. u. in coal used per ton of burned clay.

B. Heat lost in un-burned carbon in ashes.

C. Heat lost in gasification.
   1. Cubic feet of gas per pound of dry coal.
   2. Heating value of gas per cubic foot.
   3. Sensible heat in gas per pound of dry coal.
   4. Total heat in gas per pound of dry coal.

D. Heat used in burning the ware.
   1. Heat used in driving off hygroscopic water.
   2. Heat used in dehydrating the clay.
   3. Heat used in heating up clay substance.

E. Heat lost in the combustion-gases.
   1. Cubic feet of flue-gas per cu. ft. of producer-gas.
   2. Cubic feet of flue-gas per pound of dry coal.
   3. Sensible heat in flue-gas per pound of dry coal.

F. Heat lost in water-smoking gases.
   1. Cubic feet of gases per pound of dry coal.
   2. Sensible heat of gases per pound of dry coal.

G. Heat absorbed by kiln and lost by radiation.

A. Heat Introduced as Fuel.—This was calculated on the basis of pounds of coal per ton of ware burned. The total weight of coal used was divided by the total tonnage of the kiln. This gave the pounds of coal used per ton of ware. Multiplying this result by the heating value of the coal per pound as fired gave the heat introduced.

B. Heat Lost in Unburned Carbon in Ashes.—The percentage of unburned carbon in the ashes was obtained from the analysis

[1] Garland and Kratz, "Tests of a Suction Gas-Producer," Eng. Exp. Sta., Univ. of Ill., *Bull.* 50.

of the ashes. Since the earthy matter in the ashes corresponds to the "ash" of the coal, the unburned carbon in the ashes per pound of coal is readily obtained. The total ashes per pound of coal equals 100 per cent. divided by the percentage of ash in the ashes and multiplied by the percentage of ash in the coal. This, multiplied by the percentage of carbon in the ashes, gives the percentage of unburned carbon in the ashes in terms of one pound of coal. Multiplying this result by the heating value of carbon per pound gives the heat lost.

C. Heat Lost in Gasification.—Since the basis of the efficiency calculations is one pound of dry coal, the volume of producer-gas per pound of dry coal must be first obtained. The weight of carbon combined in CO_2, CO, and CH_4 per cubic foot of producer-gas is calculated from the per cent. compositions. The weight of carbon burned on the grate per pound of coal is the difference between the per cent. of carbon in the coal and the per-cent. of un-burned carbon in the ashes in terms of one pound of coal. This difference, divided by the weight of carbon per cubic foot of gas, gives the volume of gas per pound of dry coal.

The heating value of the gas per cubic foot is calculated from the per cent. composition and heating value of the combustible constituents. In obtaining the total heat of the gas per cubic foot, it is necessary to add to the heating value, the sensible heat at the temperature at which the gas enters the kiln. This is obtained from the per cent. composition, the specific heat of the constituents, and the temperature. Multiplying the total heat per cubic foot by the cubic feet per pound of coal gives the heating value of the gas per pound of coal. This value, subtracted from the heating value of one pound of coal, gives the heat lost by gasification.

D. Heat Used in Burning the Ware.—In this calculation it is assumed that the clay contains 2 per cent. hygroscopic water and three per cent. of chemical water. The total heat absorbed is, therefore, the heat used in driving off and turning into steam the hygroscopic and chemical water plus the heat used in burning the clay substance. The latter is obtained by multiplying

the weight of clay by the specific heat of clay and multiplying this result by the temperature rise.

E. Heat Lost in Combustion-Gases.—The volume of flue-gas per cubic foot of producer-gas is obtained by dividing the weight of carbon in the producer-gas per cubic foot by the weight of carbon in the flue-gas per cubic foot. This result, multiplied by the cubic feet of producer-gas per pound of dry coal, gives the volume of flue-gas per pound of dry coal. From the per cent. composition of the flue-gas, the specific heats of the constituents at the flue-gas temperatures, the temperature of the flue-gas, and the volume of flue-gas per pound of coal, the heat lost in the combustion-gases is readily calculated.

F. Heat Lost in Water-smoking Gases.—Due to the fact that the water-smoking gases left the flue at approximately atmospheric temperature, this loss was negligible and was not taken into account.

G. Heat Absorbed by Kiln and Lost by Radiation.—As the factors which enter into this calculation are so variable and the data so difficult to obtain, it is determined by the difference between 100 per cent. and the summation of the calculated factors in the heat distribution. It is plainly evident that radiation will be small in this type of kiln—due to the great thickness of the walls, the small areas subjected to high temperatures at any one time, and the high velocity with which the gases are moving through the kiln.

Data.

Coal used, as obtained from data sheets and recorded by producer firemen	524,728 lbs.
B. T. U. value of coal per pound by combustion in oxygen bomb calorimeter and furnished by the University of Illinois, Department of Applied Chemistry. Dry basis	12,630
As received	11,175
Tonnage of burned clay in the 14 chambers	1743.0 tons
Coal used per ton of burned clay	301.0 lbs.
Coal used per 1000 blocks	1400.0 lbs.
Coal used per 1000 builders	834.0 lbs.
Average weight of blocks	9.3 lbs.
Average weight of builders	5.7 lbs.

Average temperature of producer-gas flue.....	708° F.
Average temperature of waste-gas flue.....	406° F.
Average temperature of water-smoking flue.....	60° F.
Average temperature of atmospheric air.....	60° F.
Maximum temperature of burning.....	1120° C.

Analysis of Coal.

	Ultimate.		Proximate. Dry.	As received.
C.....	69.90	Fixed carbon.....	41.30	37.30
H_2.....	4.95	Volatile matter.....	44.48	38.58
O_2.....	10.29	Moisture.....	0.00	11.53
N_2.....	0.62	Ash.....	9.52	8.43
S.....	4.71	Sulphur.....	4.71	4.17
Ash.....	9.52			

Analysis of Ashes.

C = 22.24
Ash = 77.78

Average Gas Analysis (samples taken over a period of 72 hrs.).

Producer-gas.	Flue-gas.
CO_2 = 4.3	CO_2 = 3.5
CO = 24.4	O_2 = 17.1
CH_4 = 1.5	N_2 = 79.5
H_2 = 7.4	
O_2 = 0.6	
N_2 = 62.1	

Calculations.

Calculation of Producer Efficiency.—For each cubic meter of CO_2, CO and CH_4 $\frac{12}{22.4}$ kilograms of carbon are required.

$$0.043 \times \frac{12}{22.4} = 0.023 \text{ Kg. of C in } CO_2 \text{ per } M^3 \text{ of gas.}$$

$$0.244 \times \frac{12}{22.4} = 0.131 \text{ Kg. of C in CO per } M^3 \text{ of gas.}$$

$$0.015 \times \frac{12}{22.4} = 0.008 \text{ Kg. of C in } CH_4 \text{ per } M^3 \text{ of gas.}$$

0.162 Kg. of C in one M^3 of gas.

$$\frac{0.162 \times 2.2}{35.25} = 0.0101 \text{ lb. of coal per cu. ft. of gas.}$$

Carbon per lb. of coal from analysis = 0.6990 lb.

Unburned Carbon in Ashes per Lb. of dry coal = $\frac{100}{77.76} \times$ 0.0952 × 0.224 = 0.0272 lb.

Volume of producer gas per lb. of dry coal = $\frac{0.6990 - 0.0272}{0.0101}$ = 66.5 cu. ft.

Heating Value of Gas.

0.244 × 323.5 = 79.9 B. T. U. in CO per cu. ft. of gas.
0.074 × 326.2 = 24.1 B. T. U. in H_2 per cu. ft. of gas.
0.015 × 1009.2 = 15.1 B. T. U. in CH_4 per cu. ft. of gas.
Total, 119.1 B. T. U. per cu. ft. of gas.

Sensible Heat in Gas.

0.043 × 0.0257 × 708 = 0.82 B. T. U. in CO_2.
0.96 × 0.0177 × 708 = 12.00 B. T. U. in CO, O_2, CH_4, H_2 and N_2.
12.82 B. T. U. per cu. ft. of gas.

Total Heat of Producer-Gas per Pound of Dry Coal.

12.82 × 66.5 = 852 B. T. U. sensible heat
119.1 × 66.5 = 7920 B. T. U. at atmospheric conditions
8772 B. T. U. total heating value of gas per lb. dry coal.

$\frac{8772}{12630} \times 100$ = 69.4 per cent. = efficiency of the producers.

Per Cent. Heat Lost by Unburned Carbon in the Ashes = $\frac{0.0273 \times 14600 \times 100}{12630}$ = 3.15 per cent.

Per Cent. Heat Lost by Gasification in the Producers = 100 — (69.4 — 3.15) = 27.45 per cent.

Thermal Efficiency of the Kiln.

Maximum temperature of burning	= 1120° C.
Average atmospheric temperature	= 20° C.
Temperature rise of clay in chambers	= 1100° C.
Heat of dehydration of clay[1]	= 200 G. cal. per G. of water.
Latent heat of hygroscopic water[1]	= 476 G. cals. per G. of water.

[1] Clay is assumed to contain 2 per cent. hygroscopic water and 3 per cent. chemical water.

Hygroscopic water leaves at 200° C.
Dehydration temperature of clay = 650° C.
The specific heat of clay = 0.200.

Distribution of Heat in Clay.

Hygroscopic water.....	0.02 ×	180 ×	1	=	3.6 Kg. cals.
	0.02 ×	478		=	9.5 Kg. cals.
Chemical water.....	0.03 ×	0.02 ×	650	=	3.9 Kg. cals.
	0.03 ×	200		=	6.0 Kg. cals.
Clay.....	0.97 ×	0.200 ×	1100	=	213.4 Kg. cals.
Total heat required by 1 Kg. of clay				=	236.4 Kg. cals.

236.4 Kg. cals. = 425 B. T. U. per lb. of clay.
1 ton of clay requires 2000 × 425 = 850,000 B. T. U.
Heat introduced as coal per ton of clay = 301 × 11175 = 3,363,675 B. T. U.
Efficiency of kiln in terms of coal used at the producers = $\frac{850{,}000}{3{,}363{,}675}$ = 25.3 per cent.

Efficiency of Kiln in Terms of Dry Coal. $\frac{11175}{12630} \times 25.3 = 22.3$.

Percentage of Heat Used in Burning Ware = 25.3 per cent.

Heat Lost in Waste-Gas Flue.

0.244 × 1 = 0.244 cu. ft. of CO_2 from CO per cu. ft. of gas.
0.015 × 1 = 0.015 cu. ft. of CO_2 from CH_4 per cu. ft. of gas.
0.043 × 1 = 0.043 cu ft. of CO_2 from CO_2 per cu. ft. of gas.
0.302 cu. ft. of CO_2 in combustion-gas from 1 cu. ft. of producer-gas.
0.035 per cent. of CO_2 actually in combustion-gas from analysis.

$\frac{0.302}{0.035}$ = 8.63 cu. ft. of combustion-gas from 1 cu. ft. of producer-gas.

8.63 × 0.036 × 66.5 = 20.1 cu. ft. CO_2 per lb. of coal.

$8.63 \times 0.171 \times 66.5 = 92.2$ cu. ft. O_2 per lb. of coal.
$8.63 \times 0.795 \times 66.5 = 456.0$ cu. ft. N_2 per lb. of coal.
$0.074 \times 0.5 \times 66.5 = 2.5$ cu. ft. of water per lb. of coal from H_2.
$0.015 \times 2 \times 66.5 = 2.0$ cu. ft. of water per lb. of coal from H_2.
$2000 \times 0.03 = 60$ lbs. of water per ton of clay.

$\frac{60}{301} = 0.20$ lb. of water per lb. of coal from the clay.

$0.20 \times \frac{22.4}{18} \times 1.31 \times 27 = 8.8$ cu. ft of water per lb. of coal, from the clay.

13.3 cu. ft. of water in gas per lb. of coal.

$20.1 \times 0.0248 \times 406 = 201$ B. T. U. in CO_2 per lb. of coal.
$554.2 \times 0.0175 \times 406 = 3940$ B. T. U. in O_2 and N_2 per lb. of coal.
$13.3 \times 0.022 \times 406 = 119$ B. T. U. in H_2O per lb. of coal.
Total heat lost in flue-gas = 4260 B. T. U. per lb. of coal.

$\frac{4260}{12630} = 33.7$ per cent. heat lost in flue-gas.

Heat Absorbed by Kiln and Lost by Radiation.—$100 - (3.15 + 27.45 + 22.3 + 33.7) = 13.4$ per cent.

Summary.

	Per cent.
Heat lost by carbon in the ashes	3.15
Heat lost by gasification in the producer	27.45
Heat used in burning the ware	22.3
Heat lost by waste-gas	33.7
Heat lost in water-smoking gases	0.0
Heat lost by radiation and conduction	13.4
Total,	100.00

While we are skeptical as to the exactness of the data obtained and the reliability of some of the constants used in the calculations, we feel that a method is given which, with variations to suit the conditions demanded, is very well suited for the obtaining of data for a heat balance on any type of movable fire continuous kiln.

In conclusion, we wish to express our indebtedness to Mr. F. J. Hoehn for the standardization of the couples used, Mr.

R. K. Hursh for suggestions, and Mr. E. B. Rodgers, of the Alton Brick Co., for his hearty coöperation in the work.

COMMUNICATED DISCUSSIONS.

C. B. HARROP: In reading over this paper, I have been particularly interested in the figures covering kiln efficiency and heat used in burning the ware.

In calculating the "efficiency of the kiln in terms of coal used at the producers," the ratio $\frac{850,000}{3,363,675}$ is used giving an efficiency of 25.3 per cent. The numerator is calculated on the basis of 1.02 tons of green clay (including its hygroscopic water), instead of 1.052 tons of green clay (which equals 1 ton of burned clay), while the denominator is calculated clearly on the basis of 1 ton of dry clay. Recalculating this on the basis of 1.052 tons of green clay, as equalling 1 ton of burned clay, gives an efficiency of 26.1 per cent. instead of 25.3 per cent. Furthermore, this figure should not be called the efficiency of the kiln, but rather the efficiency of the kiln and producers, as part of the inefficiency is due to the particular producers employed and is not a function of the kiln.

These are small matters, however, when there comes up the difficult question of what should constitute the value of the numerator in the efficiency ratio. Mechanical efficiency is the ratio of out-put to in-put. Thermal efficiency should probably be regarded as the ratio between the amount of heat put to useful purpose (or actually doing necessary work) and the total heat applied. The question immediately arises as to what constitutes this useful purpose. If a chimney were being employed to supply kiln draft, the stack gases should have a temperature of from 400° to 600° F. If the stack temperature were reduced, by carrying the products of combustion through additional chambers, to a temperature just high enough to create the requisite draft, the heat then contained in the stack gases should certainly be considered as useful, for without it the kiln could not operate. On the other hand, any heat in excess of this would be wasted.

Even if the water-smoking gases left the kiln at 500° F. but completely saturated, this heat would represent a necessary work and should not be considered a waste or loss. On the other hand, if the water-smoking gases were not saturated, the heat represented between their temperature and the dew point would be a loss, while the difference between this loss and the total amount of heat carried would be useful.

Referring again to the calculation showing that the "percentage of heat used in burning the ware equals 25.3 per cent.," the data taken during the test show that 301 pounds of coal were burned at the producers for every ton of ware out-put. In other words, considering units and thinking of only the fundamentals of the burning operation—we set 1.05 tons of green ware at atmospheric temperature; we fire 301 lbs. of coal, then we remove one ton of burned ware at atmospheric temperature. What heat work has been accomplished? Merely that which is incident to the elimination of hygroscopic water, dehydration of the clay, and certain other pyro-chemical changes within the clay mass. If the ware had been removed from the kiln at the maximum temperature of 1120° C., then the author's calculation would have been proper—but instead of being removed from the kiln this heat was transferred by radiation, conduction, and convection (principally the latter) to the preceding chambers.

To state it differently the calculation shows that 25.3 per cent. of the heat in 301 lbs. of coal is used in burning one ton of the ware and the difference (100 — 25.3), 74.7 per cent. is wasted or lost. If this is true, and 25.3 per cent. of all the heat from the producers finds its way into the ware at its highest temperature in each and every chamber, then what becomes of the heat as these chambers of ware cool? It cannot be wasted or lost—because the 74.7 per cent. of heat from the producers covers that. The error is apparent and very large.

Using the author's figures, the "percentage of heat used in burning the ware" should be based on the heat used in driving off the hygroscopic water and dehydrating the clay and should not include any sensible heat in the ware as a result of temperature attained in the kiln.

There is one other probable source of error in this same connection, namely, the failure to include the heat required to evaporate the mechanical water in the ware when set. This usually amounts to from 1 to 3 per cent. or more—even after having passed through a good drier.

C. TREISCHEL: I have very carefully noted Mr. Harrop's discussion of this paper and, after re-checking the data, find that there is an error in the kiln efficiency calculation as he has shown.

With reference to the remainder of the discussion, however, I am obliged to take exception. Efficiency is the "ratio between out-put and in-put." Thermal efficiency, we agree, is the "ratio between the heat put to necessary work and the heat in-put." But what is the necessary work with reference to this particular kiln? The draft is produced mechanically. Is it necessary for a draft fan to operate on a gas mixture at 400° F. in order to produce draft? If not, what is the temperature? I have seen several kilns having mechanical draft in which the temperature of the waste-gases was very near atmospheric temperature. Unfortunately, there is no data available to show whether or not these kilns were more efficient than the one described in our paper. However, the operators of two of these kilns have told me that when the waste-gases leave at a higher temperature, their kilns burn more coal. If this be true, and I have every reason to believe it is true, then, if the same facts will apply to the kiln in question, all the heat leaving from the waste-gas flue above that leaving at atmospheric temperature is a loss.

There is practically no loss in the water-smoking operation—due to the fact that the gases leave at a high humidity and at atmospheric temperature.

Now then, are we much in error when we say that this kiln is only 25.3 per cent. efficient? The heat lost by gasification in the producers and in the un-burned carbon in the ashes must be called a loss. The heat leaving the kiln with the flue-gases must be regarded as lost. There remains then only the loss through radiation, etc., which is not unreasonable when one considers the thickness of the walls, crown insulation, and all other details of con-

struction of this type of kiln. Disregarding small errors, the general method of procedure seems correct.

Then, looking at the proposition from a practical standpoint, the kiln uses 201 pounds of coal in producing one ton of ware—25.3 per cent. of the fuel being used in the actual burning. As this ton of ware cools, the heat is drawn off and put to some other purpose, such as heatiug the ware in the preceding chambers—the operation being continuous. If this were not done the 301 pounds of coal might become 500 lbs., or even 600 lbs., per ton of ware, in which case the efficiency would be materially reduced.

NOTES ON THE LABORATORY TESTING OF SILICA BRICK.

By R. J. Montgomery and L. R. Office, Pittsburgh, Pa.

The importance of the accurate testing of silica brick is receiving more and more attention as is indicated by the number of articles written on the subject and the amount of work being done at the various ceramic laboratories. This discussion is intended to cover certain tests that are now quite commonly employed in determining the quality of silica brick, and in order to present the experience of the authors as an addition to the data so far published.

The recent unusual demand for silica brick has placed upon the market a number of new brands and has led to the investigation of various kinds of raw materials in order to determine their suitability for the manufacture of silica brick. In addition to the typical ganister rock, a number of other silicious materials such as chert, sand rock, and materials which grade from a fair ganister to quartz sand, loosely bonded together, are being tried. At present, there are at least two grades of silica brick on the market. The line between these grades is not sharp and their classification would vary with the purposes for which the brick are used. In a classification based upon the fusion point, we could say that Grade A would fuse at cone 32 or above and that Grade B would fuse below cone 32.

In the testing of silica brick, it must be remembered that they differ from fire clay brick in that they are composed almost entirely of one substance, silica. Therefore, the properties of the silica used govern the properties of the silica brick—this being kept in mind in the following discussion of certain important points in the testing of silica brick:

1. **Raw Materials.**—The recognized ganister rocks are known to be capable of being manufactured into silica brick of high quality, while the quality of brick manufactured from the other

kinds of silica rock is still open to question. Undoubtedly, for many purposes, the one class of material will answer as well as the other—if the brick are properly manufactured and the raw silica is of uniform quality. A picked sample of sand rock or chert may have a silica content of 96 per cent. or above, but in handling, clay and other impurities are likely to be included and the refractoriness of the brick may thus drop below cone 32. Another point of importance to be considered in selecting the silica is the physical strength of the brick after burning. Ganister rock crushes down into splintery fragments and the brick has a higher crushing strength in the cold condition than does a brick from sand rock which crushes to rounded grains. In manufacture, the sand rock brick are burned from 3 to 4 cones lower than are the ganister brick. It is possible that a sand rock brick, in which the impurities present act as a bond, although having a lower fusion point would give a brick as strong physically as one made from crushed ganister rock, providing it were burned to the proper cone. This, however, would increase the physical strength at the expense of a lower softening point.

2. **Visual Inspection.**—Field and factory inspection can do much to insure uniform quality after the raw silica has been found satisfactory. Manufacturing defects will always be present. Cracked and spongy brick are easily rejected and under-burning may be detected by linear measurements and tapping with a hammer. After the desired expansion in burning has been established, careful measurement will detect any serious under-burning. The measurement test, however, is not entirely satisfactory and should be supplemented by laboratory tests.

3. **Chemical Analysis.**—The chemical analysis is of great assistance in determining the purity of the raw material used and should be considered in connection with an actual inspection of the silica deposit or the raw material at the plant. For control work the value of chemical analyses is doubtful. To secure reliable analytical results the services of a high-grade chemist are necessary and this makes the analytical work very expensive. Tests other than the chemical analysis may be used as a check on uniformity.

4. Deformation Test.—The ordinary deformation test, using standard pyrometric cones for comparison, is of value. A silica brick of the best quality, made from pure ganister, will not soften below cone $32\frac{1}{2}$ or 33. Practically all of the brick made from chert or sand rock have a softening point of from cone 31 to 32. The softening temperature of a highly silicious material is not sharply defined and the determination is difficult owing to the high viscosity of the softened material.

5. Load Test.—The load test for silica brick, as recommended by the American Society for Testing Materials, specifies a load of 25 lbs. per sq. inch at a temperature of 1500° C. Very few failures have been recorded under these conditions and it is a question whether the test is of value unless for the testing of new brands of brick. When failure occurs, it is due to shearing or a rupture of the bond and not to a softening of the whole brick.

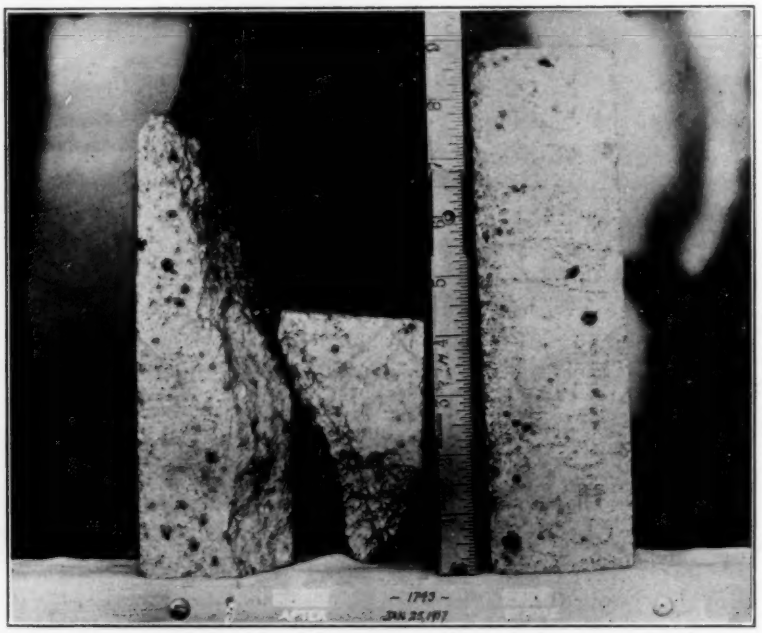

FIG. 1.

In Fig. 1 is shown a typical failure of a silica brick under the load test.

A very interesting curve is obtained from a continuous record of the expansion and contraction of a silica brick during the load test. In Fig. 2 is shown the theoretical expansion curve as given by J. Spotts McDowell[1] and the actual expansion curve as de-

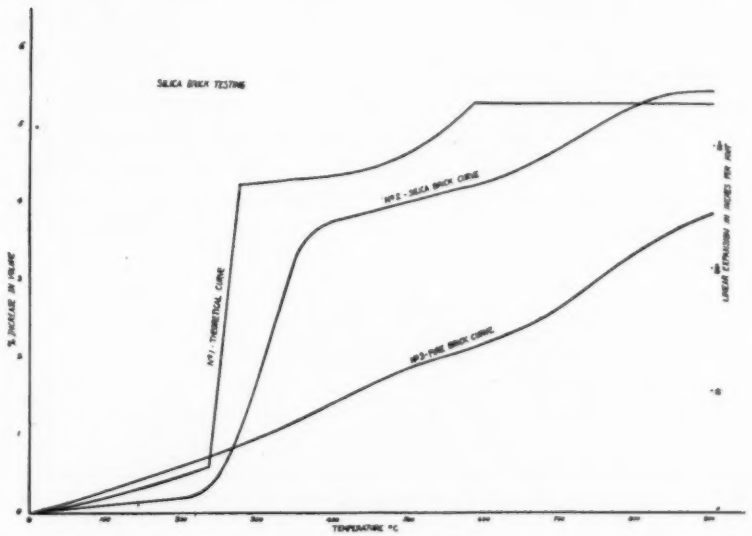
SILICA BRICK TESTING
NO 1 - THEORETICAL CURVE
NO 2 - SILICA BRICK CURVE
NO 3 - FIRE BRICK CURVE
% INCREASE IN VOLUME
LINEAR EXPANSION IN INCHES PER FOOT
TEMPERATURE °C

FIG. 2.

termined in a load test. A curve showing the behavior of a clay fire brick under load is also given. The data from which curves 2 and 3 were plotted was not definitely determined but the general trend of the curves is unquestioned.

6. Crushing Strength.—The crushing strength (cold) of a silica brick (on end) has often been used as a measure of the quality of the bond. The crushing strength of the different brands varies from 900 lbs. per sq. in. as a minimum to 3700 lbs. per sq. in. as a maximum, the average being from 1800 to 2800 lbs. per sq. in.

[1] *Bull. Am. Inst. Mining Eng.*, p. 2044, November 1916 (No. 119).

7. Specific Gravity.—D. W. Ross[1] has proven the value of the specific-gravity determination in the detection of under-burned silica brick. The method for making this determination is the one used for the apparent sp. gr. of ceramic materials—the apparent sp. gr. of a silica brick being quite close to its true sp. gr. Using a 20-gram sample and boiling for one hour to obtain saturation has been found to be satisfactory and as accurate as the two-inch cube recommended by Mr. Ross. Check determinations should be made to guard against error.

The sp.-gr. determination undoubtedly detects under-burning. Samples taken from 14 separate cars of silica brick, known to have been burned from cone 15 to 16, gave an average sp. gr. of 2.42, while samples from 12 separate cars of brick known to have been burned to cone 18 gave 2.36. Four samples of brick, thought to be under-burned, were re-burned to cone 20 and tested. The results were as follows:

No.	Before re-burning. Sp. gr.	After re-burning. Sp. gr.
1	2.44	2.38
2	2.40	2.36
3	2.39	2.36
4	2.43	2.36

8. Porosity.—The variation in the porosities of burned silica brick is slight and little use can be made of this determination. The porosity of most silica brick varies from 22 to 29 per cent.

Quite a number of other tests such as slagging, spalling, impact, etc., have been used but the authors have not enough information to warrant their detailed discussion.

Effect of Impurities.

Lime.—The lime content of silica brick is well defined, about 2 per cent. being necessary. If the lime content is less than 2 per cent. the bond will be weak and, if higher, the refractoriness of the brick will be lowered.

Alumina.—Alumina, introduced in the form of clay or other silicates, is probably the most active of all the fluxing impurities present in a silica brick. It should not exceed 1.50 per cent. Its

[1] *Trans. Am. Ceram. Soc.*, **19**, 83 (1917).

presence in excess of this amount is easily detected by a softening point below cone 32. Although a low softening point is not proof of an excessive alumina content—it should be the first impurity looked for.

Iron.—Ordinary iron discoloration seems to have less effect on the refractoriness of a silica brick than would be expected. The iron present seems to become saturated with silica and remain relatively inactive. The actual color depends considerably upon the degree of oxidation. A chemical analysis of a dark brown section of a silica brick gave 4.83 per cent. Fe_2O_3. This sample was heated to 2800° F. and held at this temperature for one hour. No spreading or local fusion was in evidence.

Two small chips from a brick showing iron spots were heated to cone 32 started or just below the softening point of the brick. The iron color seemed to distribute slightly but increased fusion or slagging was not observed. A badly discolored chip from a brick softened at about cone 32 or about half a cone below the normal softening temperature. Although the content of iron should not, in most cases, exceed 1.5 per cent., the importance of the presence of this impurity in silica brick has been exaggerated—due to its high coloring power.

The other impurities which are found present in very small amounts in silica brick are usually not considered.

Safe Operating Temperatures for Silica Brick.

There is a tendency to claim a very high operating temperature for silica brick, and statements are often made that a silica brick will not soften at 3100° or 3200° F. Statements of this kind should be qualified somewhat since in actual practice the bricks are subjected to the higher temperatures on one side only, the other side being much cooler. Owing to its high conductivity, the whole brick does not reach the temperature of the furnace—the heat being conducted away rapidly.

In order to obtain some information on this subject the following tests were made: A 3″ by 3″ by 9″ section from each of two shape bricks, manufactured by two of the largest companies in the country, were heated to 2900° F. and held at this tem-

perature for 24 hrs. The temperature during the run did not vary more than 25° F. above or below 2900° F. Both bricks softened and slumped down to the bottom of the furnace. In Fig. 3 is shown the condition of these bricks after the test.

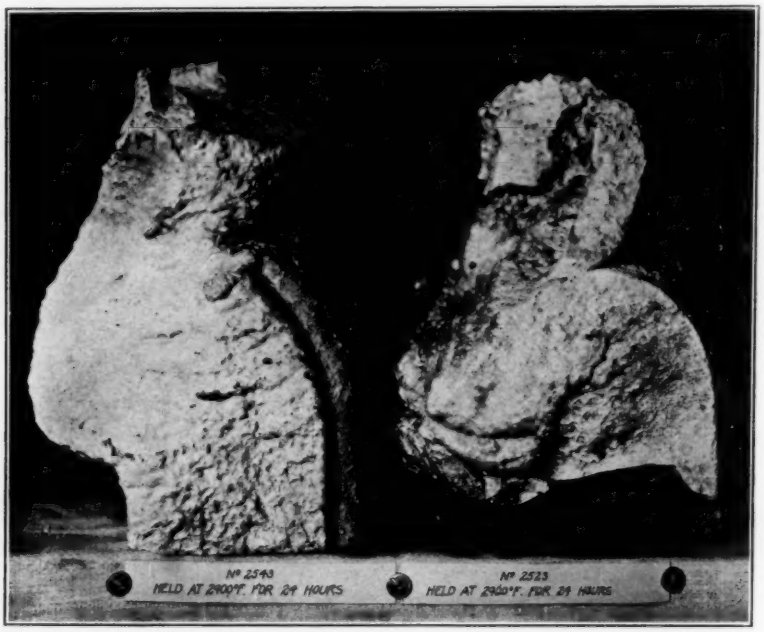

FIG. 3.

The test was repeated at 2800° F. and the bricks showed no fusion, the only effect being a whitening of the surfaces. The bricks were tested in a laboratory furnace and were exposed to the furnace temperatures from all sides—the entire mass thus attaining a practically uniform temperature. This indicates that silica brick may be subjected to higher temperatures when laid in a furnace wall in actual practice but the factor of safety lies only in the fact that the bricks do not attain this temperature throughout.

LABORATORIES OF THE H. KOPPERS CO.
AND PITTSBURGH BY-PRODUCT COKE CO.

COMMUNICATED DISCUSSIONS.

A. A. KLEIN: The authors are correct in stating that the properties of the raw silica dominate the properties of the silica brick. The complex thermal behavior of the quartz, including the modifications in which the silica is usually present in the raw material and the modifications of the silica resulting from the heat treatment, account for the peculiar properties of silica brick, for example—permanent expansion, spalling, etc.

The chemical analysis of a burned brick is of little assistance in a determination of the value of the brick—since it does not distinguish between the percentages of the various modifications of silica present. The importance of this point was shown forcibly in an investigation by the writer of the constituents of various standard brands of silica brick. The chemical analyses of the brands examined were found to show no great variations but the mineral constituents varied from, for instance, about 20 per cent. of unchanged quartz remaining in the best brick to about 80 per cent. quartz in the poorest one. In some cases, large differences in constituents were found where not only were the analyses similar but also where the same ganister formation served as the source of the raw material.

The importance of determining the constituents is evident from the great difference in the densities of the three silica modifications. These have been accurately determined by many investigators and there is no question as to the large expansion taking place when quartz inverts to cristobalite. The practical application of this is evident. If bricks contain a considerable percentage of unchanged quartz after being burned, and are used under conditions where the temperature reaches 1250° C. or higher, the inversion of the quartz in the bricks continues to a greater or lesser degree—depending upon the temperature. The expansion of the bricks keeps pace with this inversion until a dangerous condition of strain occurs—often resulting in great material damage.

It is therefore essential that a direct or indirect quantitative determination of the constituents be made. The easiest way is to obtain the apparent specific gravity of the brick—which

gives an accurate idea of the amount of unchanged quartz remaining and thus measures how much expansion has been "burned out" of the brick. This test is a most important one.

Although the chemical analysis of a burned brick is of little importance, the fact remains that it may be used, with reservations, to determine whether a raw material is suitable for silica brick-making. The authors speak of impurities causing a lowering of the refractoriness. It must be emphasized here that a silicious raw material may also be too pure. Perhaps an analogy, drawn outside the field of silica brick, would be a comparison between the Austrian and California magnesites used in the manufacture of magnesite brick.

To illustrate the effect of over purity, in a case the writer has in mind a certain quartzite containing 98 per cent. silica was used in making silica brick. It was found that, although the burning had caused sufficient quartz inversion, the bricks were "punk" and weak—due to the fact that there was not sufficient flux present to completely bond the silica grains.

It is safe to state that a rock suitable for silica brick manufacture should contain approximately 95 per cent. SiO_2, but it is well to caution against the thought that any rock having this silica content is satisfactory for this purpose. Other factors must be taken into consideration—for example— the nature of the impurities, the structure of the rock, etc.

In conclusion, the writer is of the opinion that the statement "under-burning may be roughly checked by linear measurements and tapping with a hammer," made by the authors, under the heading "Visual Inspection," should be qualified. Measuring the brick will give rough checks only with bricks made at the same plant and compared to the same standard. It has been the writer's experience that very little reliance can be placed on the "ring" of a silica brick as indicating under-burning—since well-burned and under-burned bricks may have the same ring or the same lack of ring.

R. M. Howe: Much valuable information is given by the authors of this paper—their points concerning the inspection of the raw material and the finished product being particularly

important. One man at a plant, who examines a bit of questionable raw material, who sees the cones fall during burning, who observes the care exercised during the process and how carefully the bricks are sorted, can tell more about the quality of the silica brick than a good-sized laboratory staff. His work is largely that of control and, knowing exactly what he seeks, his services are invaluable to the consumer. This is especially true when his observations are supplemented by a laboratory.

The points made by the authors in regard to the chemical analyses are well taken—as one cannot interpret the analytical results more than approximately. A silica content of 96.0 per cent., however, is rather unusual and should not be considered a necessity.

A few typical analyses of silica brick of acknowledged quality and which are the average of a large number of determinations, are given as follows:

	1.	2.	3.	4.	5.
Silica	96.05	95.85	94.96	95.58	95.31
Alumina	0.88	1.10	1.19	0.85	1.34
Iron oxide	0.79	1.04	0.85	1.26	1.31
Lime	1.80	1.80	2.02	1.77	2.04
Magnesia	0.14	0.20	0.22	0.25	0.11
Alkalies	0.39	0.15	0.38	0.13	0.27

From the above analyses it is apparent that many high grade ganister bricks contain less than 95.0 per cent. of silica. Analysis No. 1 is of a particularly pure brand of silica brick. An average silica content of 94.5 per cent. is hardly too low for a good grade of silica brick.

Softening points and load tests made on silica brick are of little value. The softening points do not vary more than 2 cones and the brick generally support a load of 25 pounds per square inch at 1500° C. Any which do not may be eliminated by other tests.

The crushing strength test on silica brick gives a large amount of information and can be verified by the modulus of rupture test—the latter not requiring such a large testing machine. These tests distinguish between well and poorly made brick, soft and hard burned brick, good and poor burning silica-bearing ma-

terial (some form a punky structure when burned), and proper and improper lime content, etc. They also serve to detect, qualitatively, the presence of any clay and other fluxes which may produce a firmer bond than ordinarily encountered.

The specific-gravity test must be conducted with care. It is generally sufficient to boil the test pieces in water at atmospheric pressure. However, the following results show that ordinary boiling is sufficient in one case and not in another: Each figure represents the average of four determinations made on samples taken from the same brick (the weight of the samples varying from 20 to 30 grams).

Brand.	Boiling ½ hr. and standing 16 hrs. in water.	Boiling 1 hr. at atmospheric pressure.	Boiling 3 hrs. at atmospheric pressure.	Boiling 3 hrs. and then 1 hr. in vacuum.
Sample No. 1....	2.212 sp. gr.	2.357 sp. gr.	2.367 sp. gr.	2.333 sp. gr.
Sample No. 2....	2.165 sp. gr.	2.312 sp. gr.	2.322 sp. gr.	2.320 sp. gr.

The following determinations also show that boiling under a vacuum for 45 minutes is about equivalent to boiling 3 hours at atmospheric pressure and then one hour in a vacuum:

	Boiling 3 hrs. at atmospheric pressure and 1 hr. in a vacuum	¾ hr. boiling in a vacuum
Sample No. 1.....	2.333 sp. gr.	2.356 sp. gr.
Sample No. 2.....	2.320 sp. gr.	2.316 sp. gr.
Average.....	2.327	2.336 sp. gr.

In the cases cited, there is evidence that sample No. 1 also needed a more thorough boiling. It was also the one which was not saturated by boiling 3 hours in air at atmospheric pressure.

It is surprising to note that a re-heating test is not mentioned by the authors. The specific-gravity test is of particular value in indicating the relative conversion of quartzite into cristobalite and tridymite and, incidentally, how well the expansion has been "burned out" of the brick. This expansion is really the important factor and can be determined directly by re-heating a sample for five hours at 1400° C.

The authors evidently distinguish between general tests and control tests. General tests include the chemical analysis, visual

inspection, load test, softening point test, specific-gravity determination, re-heating test, crushing strength and modulus of rupture tests. Many of these, including the chemical analysis, softening point test, load test and others of a like nature, need not be repeated unless in exceptional cases. However, the specific-gravity test, checked by the expansion test, will always indicate the conditions of the burn. The modulus of rupture will indicate the strength of the material. These last three tests, when used for purposes of control, are deemed sufficient for that purpose.

It is very interesting to note the temperatures at which the silica brick tested by the authors softened. In reporting the results one factor has been overlooked. The fact that a silica brick, when heated throughout, softens at 2900° F. does not mean that it cannot be heated in use at 3000° F. or 3100° F. The factor of heat conductivity has been overlooked. We have softened cone 33 in a furnace made of material softening at cone 32. This furnace was thin walled and its conductivity was high. Such a furnace, made from cone 32 material, gives good service at cone 32 and cone 33. A similar case is found in the malleable furnace and many others in which the silica bricks are often subjected to temperatures higher than their softening points. (Revised schedule of cone softening temperatures.)

This state of affairs is more true of silica brick than of fire-clay brick. At very high temperatures, the conductivity of silica brick is such that, although they may soften at 2900° F. when heated throughout, they give good service above 3000° F. if not over-insulated. A thin "glaze" forms on the hot portion of the brick but extends only for a short distance into the brick. The portions not immediately in contact with the hot zone are so protected that their softening temperature is not even approached, while the hot portion is so very viscous that it is not deformed.

MELLON INSTITUTE OF
INDUSTRIAL RESEARCH.

D. W. ROSS: The authors of this paper have indicated the importance of familiarity with the raw material from which a silica brick is made—when determining the nature of the brick

and its value for any given purpose. This point is worthy of serious attention.

The nature of the work which these authors have been doing has involved the testing of large numbers of silica brick and in this connection they have applied the specific-gravity test, mentioned in their paper, to brick made from quite a variety of raw materials. It is gratifying to the writer that they report favorably on this test. However, I am inclined to place more confidence in the results of specific-gravity tests in which the test pieces have been subjected to a vacuum (equivalent to 24″ of mercury) while immersed in hot water rather than in those in which the test pieces have been merely boiled in water. It would also appear advisable to use test pieces of a size such that determinations upon them will represent the average properties of the brick, thus avoiding the possibility of merely obtaining the properties of a few abnormal particles.

Before recommending or condemning a brick on its softening temperature, it would appear necessary to know the nature of the raw material.

In a determination of the bonding strength, the cross breaking test on silica brick placed on edge (6″ between supports) appears preferable to the compression test. Silica brick apparently fail in this test through a tearing apart of the material below the neutral axis rather than by the crushing of that above it. If, perchance, a brick fails by shearing over one of the knife edges, this can easily be detected and the results on that particular specimen may be eliminated.

R. J. MONTGOMERY: Mr. Klein's statement, as to establishing the expansion of the brick upon burning, is correct and is referred to by the authors in the statement "under-burning may be detected by linear measurements and tapping with a hammer." The quality of any silica brick that does not have a good ring is open to question and this is a good plant test—even though it does not always detect under-burned brick. A brick having a poor ring is apt to be under-burned or lacking in bond.

Mr. Howe and Mr. Ross question the method used in making

the specific-gravity determination. M. F. Beecher[1] reports considerable work on the various methods of obtaining saturation and concludes that "Saturation by boiling in water for 45 minutes to one hour is sufficient for the absorption determination," when tests are being made on the same kind of materials for comparison, and that the "treatment with a vacuum does not offer better results." The above confirms the experience of the authors. As to the size of the test pieces, used in making the specific-gravity tests, correct results may be secured from 20-gram samples providing that the results on two samples, taken from different parts of a brick, check each other.

Specific-gravity determinations on four brick, from different plants and varying quite widely in the degree of burning, gave the following results:

Sample.	Trial No.	2″ cube. Sp. gr.	1¼″ cube. Sp. gr.	¾″ cube. Sp. gr.	½″ cube. Sp. gr.
2328.....	1	2.43	2.43	2.44	2.41
	2	2.40	2.43	2.44	2.42
2150.....	1	2.27	2.29	2.30	2.28
	2	2.27	2.28	2.30	2.28
1995.....	1	2.47	2.48	2.51	2.48
	2	2.49	2.49	2.49	2.48
1997.....	1	2.31	2.33	2.34	2.32
	2	2.30	2.33	2.33	2.32

In making the above tests, cubes varying from 2″ to $^1/_2$″ were taken from each brick and subjected to the following boiling treatment:

2″ cubes weighing about 260 g. were boiled 4 hours
1$^3/_4$″ cubes weighing about 65 g. were boiled 3 hours
$^3/_4$″ cubes weighing about 18 g. were boiled 2 hours
$^1/_2$″ cubes weighing about 10 g. were boiled 1 hour

The above results indicate that if the specific-gravity determination is made on a 2″ cube, boiling will not give complete saturation—as the higher values were obtained with the smaller cubes. A piece weighing from 18 to 65 grams gave the best results. The results on a 10-gram piece are not as reliable as those secured on

[1] *Trans. Am. Ceram. Soc.*, **18**, p. 73.

the medium-sized pieces but check more closely than do those on the 260-gram pieces.

Mr. Howe's reference to flame temperatures, as high as 3000° F., reached in furnaces constructed of silica brick, brings out an important truth which has lead to the steatment by many manufacturers and users that a silica brick will actually withstand temperatures above its softening point.

The re-burning test, noted by Mr. Howe, is referred to in the paper under the paragraph on specific gravity—some results obtained by this test being tabulated.

POLYCHROME DECORATION OF TERRA COTTA WITH SOLUBLE METALLIC SALTS.

By Hewitt Wilson, Columbus, Ohio.

The terra cotta manufacturer is looking for some cheap, quick and easy way of applying two or more colors to the same piece of ware. He does not have to be as particular as the potter in the nicety of the lines and the delicacy of the colors. Most of his work is placed beyond the range of close inspection and his colored areas are comparatively large.

The method of polychroming best suited to any given order of terra cotta must be determined from (*a*) the size of the colored areas, (*b*) the number of colors or colored areas on the same piece, (*c*) the shape and finish of the outline of the colored areas, and (*d*) the respective colors to be applied. Often a combination of several methods is necessary before the order is completed.

The present methods of applying colors are:

(1) **Painting Colored Glazes onto the Required Areas with a Brush.**—This method is slow, expensive, and is liable to show streaking due to the variation in thickness of the glaze. A great many glazes of the Bristol type or variations of the same cannot be painted without developing cracks on drying caused by the unevenness of the coating—these cracks do not heal in the kiln. This method finds the greatest usefulness with glazes of low viscosity—which flow and cover well and which are usually burned to the lower temperatures. It is more adapted to small areas and small ornamental features than to large ones.

(2) **Spraying the Colored Glazes with Masques.**—By this method a paper, plaster or metal covering is placed on the part not to be coated at that time and the exposed portion is sprayed. The placing and shifting of the masques injures the freshly sprayed surfaces and leaves uneven and broken lines between adjoining colors. This is a good method for large polychrome surfaces

and features in which the colors are arranged in simple repeating design.

(3) **Overglaze Spraying.**—In the first two methods, colored glazes are placed in their respective positions. By the third method a single glaze may be sprayed over the whole piece and the overglaze colorant sprayed with a fine spray onto the desired part and brushed off the other parts. It is difficult, without the use of shields, to apply more than one color in this manner to the same piece. It works well with small, complicated designs and over large areas.[1]

(4) **Painting with Soluble Metallic Salts.**—This method was probably adopted from the underglaze decorative process—used for pottery and fine ware. In this process, soluble metallic salts are dissolved in glycerine and painted onto the biscuited or dry piece, dried to 120° C in order to set the glycerine, and fired to 800° C. The glaze is then applied and the piece burned to the proper maturing temperature.

Purdy[2] gives the following formulas for soluble underglaze colors:

		Grams.
Turquoise:	Cupric nitrate	50
	Glycerine	200
	Water	80
Light blue:	Cobalt nitrate	65
	Glycerine	115
	Water	50
Yellow:	Uranic nitrate	65
	Glycerine	60
	Water	40
Yellowish brown:	Ferric chloride	75
	Glycerine	75
	Water	50
Chamois:	Nickel nitrate	100
	Glycerine	100
	Water	100

[1] *Trans. Am. Ceram. Soc.*, **19**, 653 (1917).
[2] "Class Notes" (1912).

		Grams.
Gray:	Cobaltic nitrate	30
	Ferric chloride	10
	Glycerine	160
	Water	40
Green:	Chromic acid	100
	Water	100

For coloring terra cotta by this method, the piece is sprayed with a single glaze and the various solutions are painted onto the required areas. As the liquid quickly soaks into the dry glaze, no heating is required to set the glycerine. The ware is burned in the usual way in a single fire.

Mediums.—When water is used, save with cobalt sulphate and chromium acetate, the brush marks are too pronounced after firing. These two colorants spread easily and give uniform colors.

Glycerine is not absorbed by the dry glaze as quickly as water and allows the successive brushings to mingle. Alcohol may be used for thinning the solution. Many of the salt solutions are lacking in color so that the operator cannot detect the ground that has been covered. Common bluing or soluble dyes cause the painted areas to show distinctly.

Experimental.

Preparation.—The salts were weighed and ground together in a mortar. The required amounts of glycerine and alcohol were added and the whole ground until the salts had disssolved. The color was then applied on the dry glaze. If allowed to stand in the open, the concentration of the solutions is increased by evaporation and more coloring material will be added to the same area of base glaze with the same brush stroke. A less volatile medium than alcohol would be preferable for this reason. Many of the salts, for example some of the chlorides and sulphates, attack the carbonates in the glaze and cause bubbles and blisters. The nitrates and acetates are usually non-active in this respect.

Firing of Glazes and Colors.—After painting, the decorated trials were set, with no special precautions, in an ordinary terra cotta kiln and fired with the regular ware to cone 6–7. The glazes and underslip used were as follows:

GLAZES.

Glaze "A".....	0.268 K_2O 0.468 CaO 0.264 ZnO	0.417 Al_2O_3	2.138 SiO_2
Glaze "B".....	0.286 K_2O 0.403 CaO 0.146 ZnO 0.074 MgO 0.091 BaO	0.446 Al_2O_3	2.331 SiO_2 0.104 SnO_2
Glaze "C".....	0.238 K_2O 0.354 CaO 0.210 ZnO 0.055 MgO 0.143 BaO	0.430 Al_2O_3	2.902 SiO_2 0.141 SnO_2

VITREOUS SLIP.[1]

Standard "K".

Flint.....	194
Cornwall-stone.....	437
China clay.....	242
Ball clay.....	117
	990

"A" SERIES.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	
Cobalt sulphate.....	1.0	2.0	5.0	5.0	7.5	10.0	15.0	20.0	25.0	grams.
Water.....	100.0	100.0	100.0	50.0	50.0	50.0	50.0	50.0	50.0	cc.

Glaze "A".—The colors developed varied from light blue to dark blue. Very even colors can be produced by the use of water alone although glycerine aids in the ease of painting and insures uniformity.

Glaze "C".—This produced grayer blues than those of Glaze "A", although the range of colors is the same.

"B" SERIES.

This was the same as the "A" series save that bluing was used with the water in order to distinguish the painted areas from the unpainted. The burned colors were the same.

"C" SERIES

	1.	2.	3.	4.	5.	6.	7.	8.	9.	
Cobalt sulphate	1.0	2.0	5.0	5.0	7.5	10.0	15.0	20.0	25.0	Grams
Chromium acetate	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5	Grams
Water	100.0	100.0	100.0	50.0	50.0	50.0	50.0	50.0	50.0	Cc.

The chromium solution was too weak to change the colors from those of the "A" and "B" series and the light blue of (1) was simply deepened into the dark blues of 7, 8 and 9. A 30.0 per cent. cobalt solution (No. 7) gives the shade ordinarily desired.

"D" SERIES.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	
Cobalt sulphate	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	0.0	Grams
Uranium sulphate	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	Grams
Water	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	Cc.

Glaze "A."—(1–5) Bright blues with green streaks where the glaze and color are heavy. (6–8) Greener but not uniform. (9) the uranium yellow-green which develops well with this high zinc glaze. Uranium alone gives variable results when used on a large scale.

Glaze "B."—(1–3) Bright blue. (4–8) Good greens ranging from blue-green to bright green. (9) Good uranium yellow green.

Glaze "C."—(1–6) Blues, gray-blues, blue-grays, (7–8) grays, mottled yellow-brown (9).

Standard "K."—Greenish tinged blue or black-blue through blue-gray to gray in (9).

"E" SERIES.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	
Cobalt sulphate	5.0	4.0	3.0	2.0	1.0	1.0	1.0	1.0	1.0	Grams
Uranium nitrate	6.0	6.0	6.0	6.0	6.0	7.0	8.0	9.0	10.0	Grams
Alcohol	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "A."—(1,2,3) Blue-greens. (4,5) Good greens. (6,7,8) Yellow-greens. (9) Brown-green.

Glaze "B."—(1,2,3) Best greens. The remainder of the series are yellow and yellow-brown-greens. All are good.

Glaze "C."—(1,2) Gray-blue. (3,4) Green-gray. (5,6) Green-brown. (7,8,9) Dark green-brown.

Standard Slip "K."—Blues to gray-browns. (5,6,7) Have a slight green tinge. (3) Was flashed and a blue-black.

"F" Series.

	1.	2.	3.	4.	5.
Antimony chloride.....	10.0	10.0	10.0	10.0	10.0 Cc.
Rutile.....	0.0	0.5	1.0	1.5	2.0 Grams
Glycerine.....	10.0	10.0	10.0	10.0	10.0 Cc.
Soda ash.....	6.0	6.0	6.0	6.0	6.0 Grams

Glaze "A."—(1,2) Gray. (3,4,5) Yellow scummed.

Glaze "B."—(1) No color, scummed surface. (2) Faint orange tinge. (3) Spotted orange. (4) Orange but variable. (5) Crawled, variable rutile orange.

Glaze "C."—(1,2) Light gray. (3,4,5) Best yellows of all glazes. The acid in the antimony chloride attacks the carbonates of the glazes and causes blistering. Hence the soda ash was added to neutralize the acid without success.

Standard "K."—Yellow with good increase of orange colors with the series. Blistering.

"G" Series.

	1.	2.	3.	4.	5.
Cobalt sulphate.....	1.0	1.0	1.0	1.0	1.0 Grams
Uranium nitrate.....	6.0	6.0	6.0	6.0	6.0 Grams
Iron chloride.....	0.0	1.0	2.0	4.0	8.0 Grams
Alcohol.....	10.0	10.0	10.0	10.0	10.0 Cc.
Glycerine.....	10.0	10.0	10.0	10.0	10.0 Cc.

Glaze "A."—(1,2) Good greens. (3,4,5) Give lighter and browner colors.

Glaze "B."—(1) Dark almost black-green. (5) Yellow-brown-green. Good even colors.

Glaze "C."—Dark gray-greens to greenish browns. The iron affords an individual brown color in spots.

Standard "K."—(1) Gray-black to light neutral gray. (5) Iron acts as a diluent and does not intensify the color.

"H" SERIES.

	1.	2.	3.	4.	5.	
Cobalt sulphate	1.0	1.0	1.0	1.0	1.0	Grams
Uranium nitrate	6.0	6.0	6.0	6.0	6.0	Grams
Iron chloride	2.0	2.0	2.0	2.0	2.0	Grams
Chromium acetate	0.0	0.5	1.0	2.0	4.0	Grams
Alcohol	10.0	15.0	15.0	15.0	15.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "A."—(1,2) Uranium greens. (3,4,5) Green-browns.

Glaze "B."—(1,2) Yellow-green. (3,4) Yellow-brown. (5) Buff-brown.

Glaze "C."—(1) Gray-green. (2) Brown-green. (3,4,5) Browns.

Standard "K."—(1) Dark blue-gray. (2,3,4,5) Grays and blacks.

"I" SERIES.

	1.	2.	3.	4	5.	
Uranium nitrate	4.0	2.0	1.0	0.5	0.0	Grams
Iron chloride	0.0	0.5	1.0	2.0	4.0	Grams
Alcohol	10.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "A."—(1,2) Varying uranium greens. (3) Light yellow. (4,5) Light buffs.

Glaze "B."—(1,2) More orange than Glaze "A." (3) Bright yellow. (4,5) Light buffs.

Glaze "C."—(1,2) Yellow and brown-green. (3) Light buff-yellow. (4,5) Brown edged yellow-buffs.

Standard "K."—(1,2) Blue-grays. (3,4) Light buffs. (5) Good tan.

"J" SERIES.

	1.	2.	3.	4.	5.	
Tin chloride	5.0	10.0	15.0	20.0	25.0	Grams
Chromium acetate saturated in alcohol	0.0	5.0	5.0	5.0	5.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.
Alcohol	5.0	7.5	15.0	20.0	25.0	Cc.

Glazes "B" and "C."—Pink colors but crowfooted, dry and blistered. Some of the blistering occurs in the application. "K" series is good with (4) of "J" series.

"K" Series.

	1.	2.	3.	4.	5.	
Tin chloride	20.0	20.0	20.0	20.0	20.0	Grams
Chromium acetate saturated in alcohol	0.0	2.0	4.0	8.0	16.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.
Alcohol	25.0	23.0	21.0	17.0	9.0	Cc.

Glaze "B."—(1) Light pink but crowfooted. (2–5) Increasing pinkness. Very good colors.

Glaze "C."—(1,2) Light pinks, dry glaze. (3,4,5) Increasing pinkness but with a buff tinge.

"L" Series.

	1.	2.	3.	4.	5.	
Tin chloride	20.0	20.0	20.0	20.0	20.0	Grams
Chromium acetate (5 per cent. in H_2O)	2.0	4.0	8.0	16.0	25.0	Cc.
Alcohol	8.0	6.0	2.0	0.0	0.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—Pink colors are good and equal to those of "K" series.

Glaze "C."—(1,2) Light pink, liable to crowfoot, blister and be dry. (3,4,5) Very light pink, lighter than "K" series.

"M" Series.

	1.	2.	3.	4.	5.	
Manganese sulphate	5.0	10.0	15.0	20.0	25.0	Grams
Alcohol	5.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Standard "K."—(1) Light gray. (2) Dark brown glazed surface. (3–5) Increasing dark brown variegated colors which can be used if the running of the glaze is allowed for. Manganese lowers the viscosity considerably.

Glazes "B" and "C."—(1) Medium brown to streaked browns and blacks in (3,4,5). Manganese sulphate melts into a glaze by itself, whether in standard or glaze.

"N" Series.

	1.	2.	3.	4.	5.	
Potassium permanganate	5.0	10.0	15.0	20.0	25.0	Grams
Alcohol	5.0	10.0	10.0	16.0	25.0	Cc.
Glycerine	10.0	10.0	15.0	18.0	18.0	Cc.

These mixtures become warm with emission of a white vapor and bubble when mixed with alcohol. This does not work as well as the sulphate, showing blistering, peeling and dryness. Colors are not even and brush marks show.

"O" Series.

	1.	2.	3.	4	5.	
Potassium permanganate	0.0	0.5	1.0	1.5	2.0	Grams
Cobalt sulphate	1.0	1.0	1.0	1.0	1.0	Grams
Iron chloride	6.0	6.0	6.0	6.0	6.0	Grams
Chromium acetate	0.5	1.0	1.5	2.0	2.5	Grams
Glycerine	10.0	10.0	12.0	15.0	15.0	Cc.
Alcohol	5.0	5.0	7.5	10.0	10.0	Cc.

Glaze "B."—Light and darker mottled brown-grays to a dark brown.

Glaze "C."—Good red-browns, the color varying with the painting.

Standard "K."—(1) Gray. (2,3,4,5) are dark browns and blacks.

"P" Series.

	1.	2.	3.	4.	5.	
Cobalt sulphate	5.0	3.0	1.0	1.0	1.0	Grams
Iron chloride	6.0	6.0	6.0	8.0	10.0	Grams
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.
Alcohol	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—(1,2) Violet-blues. (3) Light blue-gray. (4,5) Buff, blue.

Glaze "C."—(1,2) Gray-blues. (3,4,5) Light blue-grays.

Standard "K."—(1) Flashed, blue-gray. (2) Dark green-black flashed. (3,4,5) Good browns.

"Q" Series.

	1.	2.	3.	4.	5.	
Rutile	0.2	0.5	1.0	2.0	4.0	Grams
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—(1,2) Faint streaks of yellow. (3) Darker and streaked.

Glaze "C."—(4,5) Rutile yellow-brown, badly wrinkled.

Standard "K."—Good even colors ranging from light brown to red-brown. May be used. As the rutile did not dissolve, this was an overglaze decoration rather than a soluble stain.

"R" SERIES.

	1.	2.	3	4.	5.	
Iron chloride	2.0	4.0	8.0	16.0	25.0	Grams
Alcohol	10.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—(1,2) Very light yellow. (3) Light brown. (4,5) Dark red-brown.

Glaze "C."—(1,2) Light buffs. (3,4,5) Increasing red-browns.

Standard "K."—(1,2,3) Light gray-buffs. (4,5) Red-browns, varying.

All are good colors but vary as the iron volatilizes in burning.

"S" SERIES.

	1.	2.	3.	4.	5.	
Copper sulphate	2.0	4.0	8.0	16.0	25.0	Grams
Alcohol	10.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—Colors duplicate those of glaze "C" but show more black and not too much good green. This is just the reverse of the uranium series in which Glaze "C" gives the poor greens.

Glaze "C."—(1) Light copper-green, good and uniform. (2) Varying copper-green, fair. (3,4,5) Green-blacks and black. No defects.

Standard "K."—(1,2) Just faintly off color. (3) Light greenish shades, blistered. (4,5) Uniform black.

"T" SERIES.

	1.	2.	3.	4	5.	
Nickel sulphate	2.0	4.0	8.0	16.0	25.0	Grams
Alcohol	10.0	10.0	10.0	10.0	10.0	Cc.
Glycerine	10.0	10.0	10.0	10.0	10.0	Cc.

Glaze "B."—(1) Good nickel-purple, uniform. (2) Lighter than (1). (3) Purplish gray. (4,5) Peeled and showing unmelted green dust which rubs off easily.

Glaze "C."—(1,3) Good browns, uniform. (4,5) Unmelted, rub off.

Standard "K."—Good browns. (4,5) Greenish unmelted dust.

From the above series, the best colors were selected and used in painting ornamental terra cotta, including bits of scenery.

An unskilled man, not used to handling a brush, did very good work after a few days' practice.

RESULTS.

Colors with the Glazes.

Blue.—Good blues are very easily produced with cobalt sulphate in all of the glazes. Varying the amount of the sulphate from 0.5 g. to 30.0 g. per 100 cc. of water will give a range from a very light sky-blue to the ordinary deep blue. Beyond this amount the color darkens rapidly to blue-blacks.

Green.—Because of the zinc used in the glazes of this study, chromium salts gave tans and browns which are stable, uniform, and easy to use. However, the green from chromium in zincless glazes was not good and could not be relied upon.

The best green colors were produced from the uranium-cobalt combination in the mat glazes "A" and "B". The gloss glaze "C" gave gray-greens. The best proportions were uranium nitrate 6 grams, cobalt sulphate 1.0 to 3.0 grams, alcohol 10 cc. and glycerine 10 cc.

The copper-greens were variable and faded. However, Glaze "C", which gave poor greens with cobalt and uranium, gave better results with the copper.

Pink.—Uniform light pink colors can be produced in the above glazes with mixtures of tin chloride and chromium acetate. 20 grams of tin chloride, 16 cc. of a saturated solution of chromium acetate in alcohol, with 10 cc. of glycerine and 9 cc. of alcohol, gave good light pinks.

Browns.—Manganese sulphate 10 g., alcohol 10 cc. and glycerine 10 cc. gave fair browns. If made stronger than this or if painted heavily, it will darken from brown to black and run when applied on an inclined surface. If more dilute the manganese will produce good grays. These browns, grays and blacks may be varied by blending with cobalt, iron and chromium as in the "O" series.

Nickel Sulphate with Glazes "A" and "B" produced light purple and gray colors[1] but with Glaze "C" it gave good uniform browns.

Chromium Acetate in a glaze containing zinc gives good uniform tans and browns.

Iron Chloride gave red-browns but these were variable at the firing temperature.

Yellow.—Dilute uranium sulphate or nitrate alone or with iron chloride gave promise of fair light yellow shades. However, when tried out further they were not very reliable.

Gray.—This may be produced from several sources depending on the shade desired. Blue-grays were obtained in Glaze "C" with cobalt and uranium—the uranium content being lower and the cobalt higher than used for the production of green colors. (See Series "D.")

Violet.—Cobalt and iron in "P" series gave violet and blue-grays with a ratio of cobalt sulphate to iron chloride varying from 5 : 6 to 1 : 10, respectively. Dilute manganese gives brownish grays.

Colors with Vitreous Slip "K."

Blues are easily obtained with cobalt sulphate. Most of the other salts or combinations give grays, browns or blacks. The colors are not as bright as those developed in the glazes.

Browns.—Dilute uranium gave gray, strong uranium gave gray-browns.

Uranium and cobalt combinations gave blue and green-blacks.

Iron gives buffs and red-browns.

Manganese gives grays, browns and blacks, of different shades, however, than those produced in the glazes.

[1] *Trans. Am. Ceram. Soc.*, **14**, 141 (1912).

Rutile painted on the surface with glycerine gives good light buffs and buff-browns.

Copper sulphate gives light green-grays running into blacks.

Nickel gave good browns.

In conclusion, we wish to state that the Denver Terra Cotta Company has also used this method on shop orders with success and in fact is the pioneer for this method of color decoration of terra cotta on a large scale.

OHIO STATE UNIVERSITY.

DISCUSSION.

MR. BURT: I would like to ask Mr. Wilson if he has not experienced large variations in color when using the glazes containing the soluble salts. In other words—does not the personal factor influence the depth of color secured by spraying with the brush?

MR. WILSON: The amount of solution on the brush, the speed of the brush across the absorbent surface of the dry glaze and the repeated number of strokes over the same surface, all have an influence on the amount of coloring material added to a given square inch of glaze surface.

If the concentration of the solution is so made that a moderate soaking action of the glaze surface is necessary to produce the desired depth of color, more uniform results can be expected both in regard to the shade and to the elimination of the brush markings. This aids in the solution of the personal factor problem.

MR. TRUMAN: I should like to ask Mr. Wilson if, in weighing out the soluble salts, he did not experience some difficulties through their absorption of moisture from the atmosphere? I have experienced this difficulty in weighing out chloride of iron.

MR. WILSON: Some of the salts absorb moisture very rapidly. They must be weighed very quickly.

MR. TRUMAN: In some of my work in which soluble salts were used, I found it advantageous to add the salts in the form of saturated solutions of predetermined specific gravity.

MR. MINTON: I would ask Mr. Wilson whether he has determined the relative behavior of cobalt borate and cobalt sulphate in his glaze work? I understand that the cobalt borate is to be preferred.

MR. WILSON: I have encountered some blistering of the glazes when using chromium sulphate. I did not experience this difficulty when using cobalt sulphate. I can see no objection to the use of cobalt borate although I have not used it.

MR. RADCLIFFE: My experience has been similar to that of Mr. Truman's in regard to the variation in color, and I have found that the best method was to use solutions of the soluble salts, controlling their specific gravities by means of a hygrometer. In this way the variation in color was reduced to a minimum. Some of these soluble salts do cause blistering of the glazes during their application—due to the acid in the salts. This difficulty may be overcome by the addition of a metallic oxide to the solution and neutralizing the acid.

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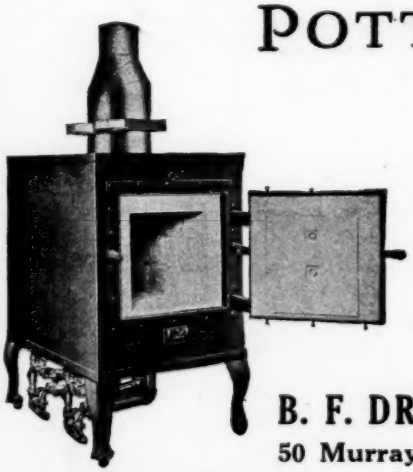

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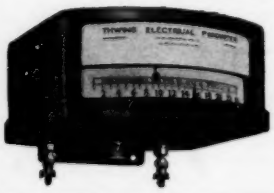
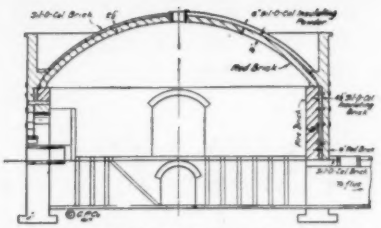


The use of a Thwing Pyrometer System is a protection against fuel waste and ruined product from improper burning, and is a big help in getting better results with inexperienced men. Ask for our latest catalog.

THWING INSTRUMENT CO.

3335 Lancaster Ave. PHILADELPHIA



Section of Ceramic Kiln insulated with SIL-O-CEL.

SIL-O-CEL

TRADE MARK REGISTERED U.S. PATENT OFFICE

MADE FROM CELITE

"More Product with Less Fuel"

SIL-O-CEL Insulation, Brick and Powder, applied to kilns actually increases their out-put and saves fuel.

Better temperature control and more uniform interior temperatures invariably result from SIL-O-CEL Insulation.

Write for Bulletin B-5

We would like to tell you more of the advantages of SIL-O-CEL Insulation and show you some facts. Write us about your kilns.

CELITE PRODUCTS COMPANY

New York Chicago Pittsburgh Los Angeles San Francisco

Quality *Uniformity* *Experience*

Edgar QUALITY *Clays*

REALLY washed—Highest percentage clay substance

Brands	Produced by
Edgar Florida Kaolin	*Edgar Plastic Kaolin Co.*
Edgar Georgia Paper Clay and Kaolin	*Edgar Brothers Co.*
Lake County Florida Clay	*Lake County Clay Co.*

One Management—Office, Metuchen, N. J.

AMERICAN NINE FOOT DRY PAN

Here's one of our famous line of pans. They are built to handle a lot of clay and they do it. Nothing shoddy about this pan, that's why it makes good and works steadily without trouble. Get our pan printed matter. We surely have a pan to do your work better and with less trouble and expense than you are now doing it. Let us prove it.

THE AMERICAN CLAY MACHINERY CO.

BUCYRUS, O.

DURABILITY

Is the vital quality of the brick that are used in copper furnaces and open-hearth steel furnaces. And that's why the Laclede-Christy Bauxite Brick have proven so remarkably popular--they stand the test.

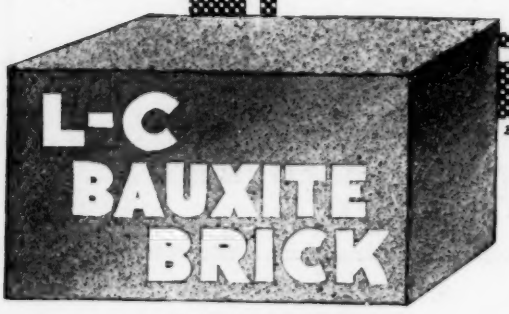
L-C Bauxite Brick are being used as a substitute for Magnesite Brick with great success--they are cheaper and in many cases have proven more durable.

You can't afford to gamble on refractories of inferior quality **now**. Shut-downs at this time are disastrous. Be on the safe side--use L-C Bauxite Brick in the walls of your furnaces. Tell us your requirements and let us quote you prices.

LACLEDE-CHRISTY

Everything in Clay Products

Railway Exchange Bldg., St. Louis, Mo.



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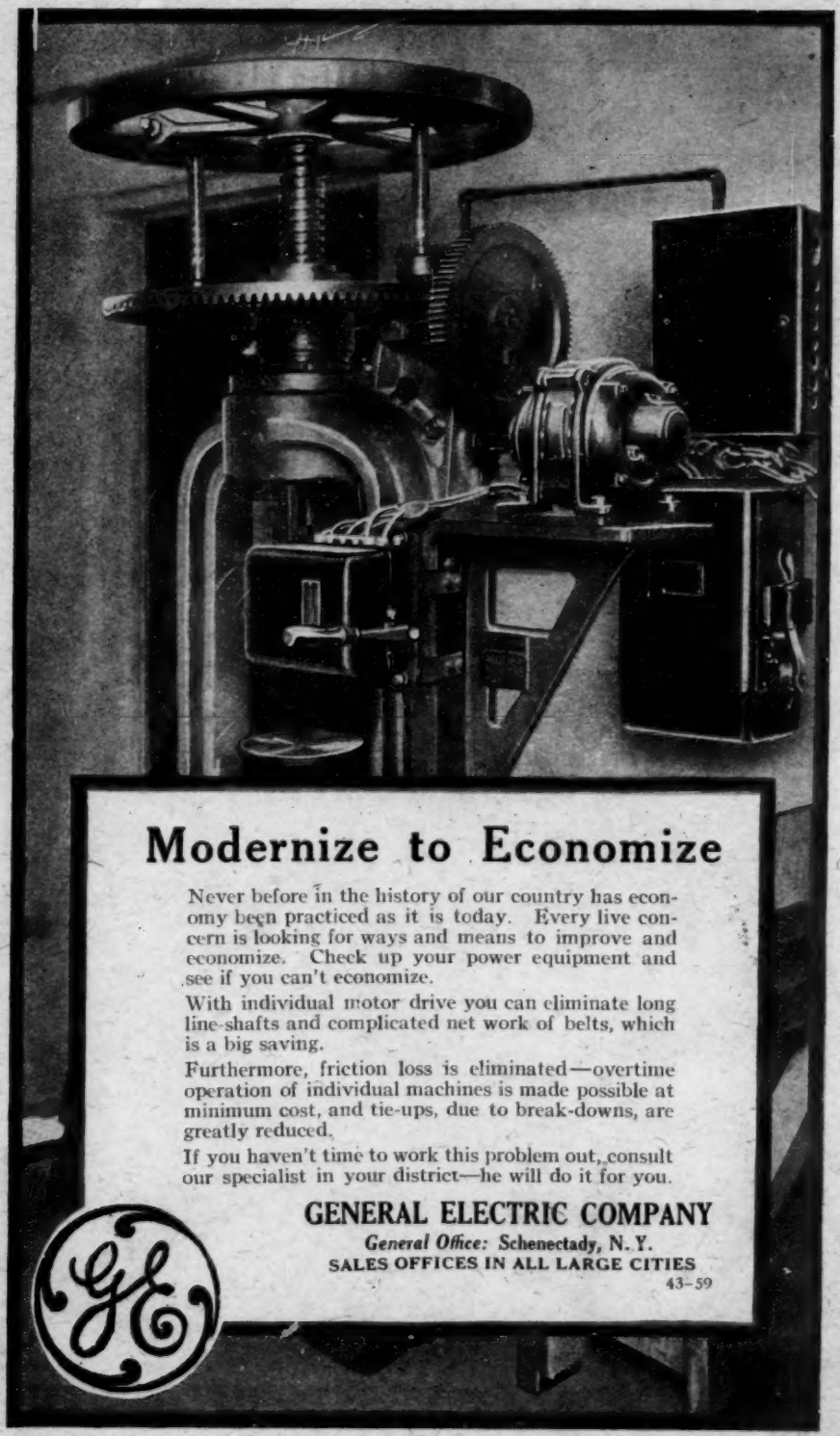
THE AMERICAN'S CREED.

***I believe** in the United States of America as a government of the people, by the people, for the people; whose just powers are derived from the consent of the governed; a democracy in a republic; a sovereign nation of many sovereign states; a perfect union, one and inseparable; established upon these principles of freedom, equality, justice and humanity for which American patriots sacrificed their lives and fortunes.*

***I therefore believe** it is my duty to my country to love it; to support its constitution; to obey its laws; to respect its flag and to defend it against all enemies.*

—WILLIAM TYLER PAGE



Modernize to Economize

Never before in the history of our country has economy been practiced as it is today. Every live concern is looking for ways and means to improve and economize. Check up your power equipment and see if you can't economize.

With individual motor drive you can eliminate long line-shafts and complicated net work of belts, which is a big saving.

Furthermore, friction loss is eliminated—overtime operation of individual machines is made possible at minimum cost, and tie-ups, due to break-downs, are greatly reduced.

If you haven't time to work this problem out, consult our specialist in your district—he will do it for you.

GENERAL ELECTRIC COMPANY

General Office: Schenectady, N. Y.

SALES OFFICES IN ALL LARGE CITIES

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